

## **CHAPTER 13**

### **CONCRETE COLUMNS**

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## CHAPTER 13

### CONCRETE COLUMNS

#### 13.1 INTRODUCTION

Columns are structural elements that support the superstructure, transfer vertical loads from superstructure to foundation, and resist the lateral loads acting on the bridge due to seismic and various service loads.

#### 13.2 TYPES OF COLUMNS

Columns are categorized along two parameters (Chen, 2014 and MacGregor, 1988): shape and height:

- Columns sections are usually round, rectangular, solid, hollow, octagonal, or hexagonal.
- Columns may be short or tall. The column is called either short or tall according to its effective slenderness ratio ( $Kl_u/r$ ).

where:

$K$  = effective length factor

$l_u$  = unsupported length of a compression member

$r$  = radius of gyration

#### 13.3 DESIGN LOADS

The considered design loads as specified in AASHTO 3.3.2 are:

- Dead loads (DC)
- Added dead loads (DW)
- Design vehicular live loads:
  1. Design vehicle HL-93 shall consists of a combination of (Truck + Lane) or (design tandem + Lane) including dynamic load allowance (IM).
  2. Permit vehicle (P15) including the dynamic load allowance (IM).
- Wind loads (WS, WL)

- Braking force (BR)
- Thermal effects (TU)
- Prestress shortening effects (CR, SH)
- Prestressing secondary effects (PS)

## **13.4 DESIGN CRITERIA**

Columns are designed for Service, Strength, and Extreme Event limit states (AASHTO, 2012 and Caltrans, 2014). The Extreme Event I limit state must be in accordance with the current the Caltrans Seismic Design Criteria (*SDC*) version 1.7 (Caltrans, 2013). Columns should be designed as ductile members to deform inelastically for several cycles without significant degradation of strength or stiffness under the design earthquake demand (see *SDC* seismic design criteria chapters 3 and 4 for more details). Columns supporting a superstructure that is built using balanced cantilevered construction, or other unusual construction loads, are not addressed herein.

### **13.4.1 Limit States**

As stated above, columns are designed for three limit states:

- Strength Limit State
- Service Limit State
- Extreme Event Limit State

### **13.4.2 Forces**

Bridge columns are subjected to axial loads, bending moments, and shears in both the longitudinal and transverse directions of the bridge.

## **13.5 APPROXIMATE EVALUATION OF SLENDERNESS EFFECTS**

The slenderness of the compression member is based on the ratio of  $Kl_u/r$  (AASHTO 5.7.4.3), while the effective length factor,  $K$  (AASHTO 4.6.2.5), is to compensate for rotational and transitional boundary conditions other than pinned ends.

Theoretical and design values of  $K$  for individual members are given in AASHTO Table C4.6.2.5.-1.

Slenderness effect is ignored if:

$$Kl_u/r < 22 \quad \text{(members not braced against sidesway)}$$

$$Kl_u/r < 34 - 12 (M_1 / M_2) \quad (\text{members braced against sidesway})$$

where:

$M_1$  = smaller end moment, should be positive for single curvature flexure

$M_2$  = larger end moment, should be positive for single curvature flexure

$l_u$  = unsupported length of a compression member

$r$  = radius of gyration

= 0.25 times the column diameter for circular columns

= 0.3 times the column dimension in the direction of buckling for rectangular columns

If slenderness ratio exceeds the above-mentioned limits, the moment magnification procedure (AASHTO 4.5.3.2.2b) can approximate the analysis.

*Note:* If  $Kl_u/r$  exceeds 100, columns may experience appreciable lateral deflections resulting from vertical loads or the combination of vertical loads and lateral loads. For this case, a more detailed second-order non-linear analysis should be considered, including the significant change in column geometry and stiffness.

### 13.5.1 Moment Magnification Method

The factored moments may be increased to reflect effects of deformation as follows:

$$M_c = \delta_b M_{2b} + \delta_s M_{2s} \quad (\text{AASHTO 4.5.3.2.2b-1})$$

where:

$M_c$  = magnified factored moment

$M_{2b}$  = moment on compression member due to factored gravity loads that result in no sideways, always positive

$M_{2s}$  = moment on compression member due to factored lateral or gravity loads that result in sideways,  $\Delta$ , greater than  $l_u/1500$ , always positive

$\delta_b$  = moment magnification factor for compression member braced against sideways

$\delta_s$  = moment magnification factor for compression member not braced against sideways

The moment magnification factors ( $\delta_b$  and  $\delta_s$ ) are defined as follows:

$$\delta_b = \frac{C_m}{1 - \frac{P_u}{\phi_k P_e}} \geq 1 \quad (\text{AASHTO 4.5.3.2.2b-3})$$

$$\delta_s = \frac{1}{1 - \frac{\sum P_u}{\phi_k \sum P_e}} \quad (\text{AASHTO 4.5.3.2.2b-4})$$

For members braced against sideway  $\delta_s$  is taken as one unless analysis indicates a lower value. For members not braced against sideway  $\delta_b$  is to be determined as for a braced member and  $\delta_s$  for an unbraced member.

$P_u$  = factored axial load

$P_e$  = Euler buckling load, which is determined as follows:

$$P_e = \frac{\pi^2 E_c I}{(Kl_u)^2}$$

$E_c$  = the elastic modulus of concrete

$I$  = moment of inertia about axis under consideration

$\phi_k$  = stiffness reduction factor; 0.75 for concrete members and 1 for steel members

$C_m$  = a factor, which relates the actual moment diagram to an equivalent uniform moment diagram, is typically taken as one

However, in the case where the member is braced against sidesway and without transverse loads between supports,  $C_m$  may be based on the following expression:

$$C_m = 0.6 + 0.4 \frac{M_{1b}}{M_{2b}} \quad (\text{AASHTO 4.5.3.2.2b-6})$$

To compute the flexural rigidity  $EI$  for concrete column in determining  $P_e$ , AASHTO 5.7.4.3 (AASHTO, 2012) recommends that the larger of the following be used:

$$EI = \frac{\frac{E_c I_g}{5} + E_s I_s}{1 + \beta_d} \quad (\text{AASHTO 5.7.4.3-1})$$

$$EI = \frac{\frac{E_c I_g}{2.5}}{1 + \beta_d} \quad (\text{AASHTO 5.7.4.3-2})$$

where:

$I_g$  = the gross moment of inertia (in.<sup>4</sup>)

$E_s$  = elastic modulus of reinforcement (ksi)

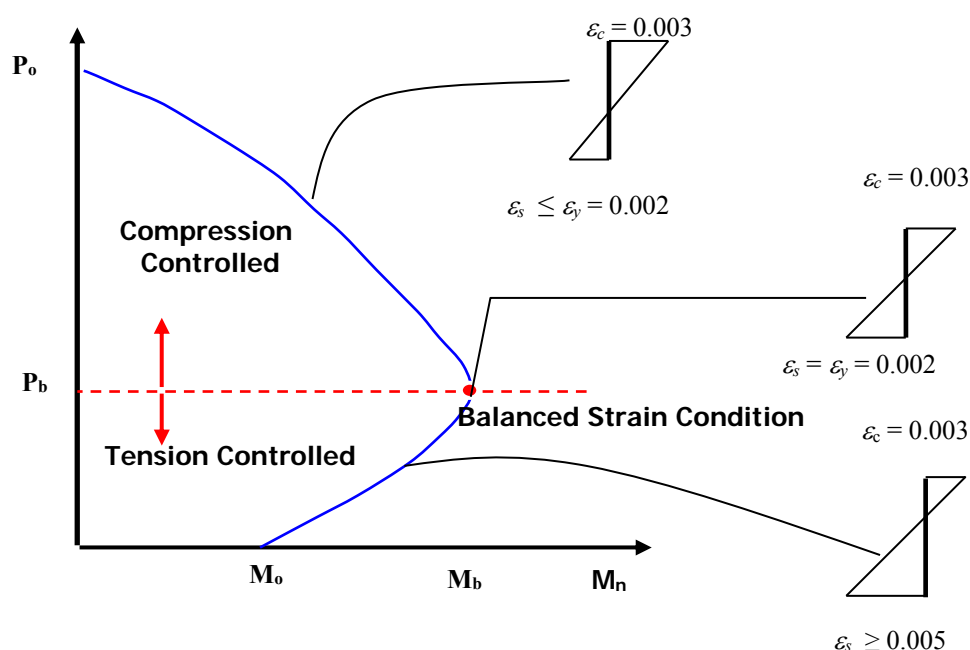
$I_s$  = moment of inertia of longitudinal steel about neutral axis (ksi)

$\beta_d$  = ratio of maximum factored permanent load moment to the maximum factored total load moment, always positive

## 13.6 COMBINED AXIAL AND FLEXURAL STRENGTH

### 13.6.1 Interaction Diagrams

Flexural resistance of a concrete member is dependent upon the axial force acting on the member. Interaction diagrams for a reinforced concrete section are created assuming a series of strain distributions and computing the corresponding moments and axial forces. The results are plotted to produce an interaction diagram as shown in Figure 13.6-1.



**Figure 13.6-1 Typical Strength Interaction Diagram for Reinforced Concrete Section with Grade 60 Reinforcement**

When combined axial compression and bending moment act on a member having a low slenderness ratio and where column buckling is not a possible mode of failure, the strength of the member is governed by the material strength of the cross section. For this so-called short column, the strength is achieved when the extreme concrete compression fiber reaches the strain of 0.003. In general, one of three modes of failure will occur: tension controlled, compression controlled, or balanced strain condition (AASHTO 5.7.2.1). These modes of failure are detailed below:

- Tension controlled: Sections are tension controlled when the net tensile strain in the extreme tension steel is equal to or greater than 0.005 just as the concrete in compression reaches its assumed strain limit of 0.003.
- Compression controlled: Sections are compression controlled when the net tensile strain in the extreme tension steel is equal to or less than the net tensile strain in the reinforcement ( $\epsilon_y = 0.002$ ) at balanced strain condition at the time the concrete in compression reaches its assumed strain limit of 0.003.
- Balanced strain condition: Where compression strain of the concrete ( $\epsilon_c = 0.003$ ) and yield strain of the steel (for Grade 60 reinforcement  $\epsilon_y = 0.002$ ) are reached simultaneously, the strain is in a balanced condition.

### 13.6.2 Pure Compression

For members with spiral transverse reinforcement, the axial resistance is based on:

$$P_r = \phi P_n = \phi 0.85 P_o = \phi (0.85) [0.85 f'_c (A_g - A_{st}) + A_{st} f_y] \quad (\text{AASHTO 5.7.4.4-2})$$

For members with tie transverse reinforcement, the axial resistance is based on:

$$P_r = \phi P_n = \phi 0.8 P_o = \phi (0.8) [0.85 f'_c (A_g - A_{st}) + A_{st} f_y] \quad (\text{AASHTO 5.7.4.4-3})$$

where:

$P_r$  = factored axial resistance

$P_n$  = nominal axial resistance, with or without flexure

$\phi$  = resistance factor specified in AASHTO 5.5.4.2

$P_o$  = nominal axial resistance of a section at zero eccentricity

$f'_c$  = specified strength of concrete at 28 days, unless another age is specified

$A_g$  = gross area of section

$A_{st}$  = total area of main column reinforcement

$f_y$  = specified yield strength of reinforcement

### 13.6.3 Biaxial Flexure

AASHTO 5.7.4.5 specifies the design of non-circular members subjected to biaxial flexure and compression based on the stress and strain compatibility using one of the following approximate expressions:

For the factored axial load,  $P_u \geq 0.1f'_cA_g$

$$\frac{1}{P_{rxy}} = \frac{1}{P_{rx}} + \frac{1}{P_{ry}} + \frac{1}{P_o} \quad (\text{AASHTO 5.7.4.5-1})$$

where:

$$P_o = 0.85f'_c(A_g - A_{st}) + A_{st}f_y \quad (\text{AASHTO 5.7.4.5-2})$$

For the factored axial load,  $P_u \leq 0.1f'_cA_g$

$$\frac{M_{ux}}{M_{rx}} + \frac{M_{uy}}{M_{ry}} \leq 1 \quad (\text{AASHTO 5.7.4.5-3})$$

where:

$P_{rxy}$  = factored axial resistance in biaxial flexure

$P_{rx}$  = factored axial resistance determined on the basis that only eccentricity  $e_y$  is present

$P_{ry}$  = factored axial resistance determined on the basis that only eccentricity  $e_x$  is present

$P_u$  = factored applied axial force

$M_{ux}$  = factored applied moment about  $x$  axis

$M_{uy}$  = factored applied moment about  $y$  axis

$M_{rx}$  = uniaxial factored flexural resistance of a section about  $x$  axis corresponding to the eccentricity produced by the applied factored axial load and moment

$M_{ry}$  = uniaxial factored flexural resistance of a section about  $y$  axis corresponding to the eccentricity produced by the applied factored axial load and moment

## 13.7 COLUMN FLEXURAL DESIGN PROCEDURE

Column flexure design steps for permanent and transient loads are presented in the following sub-sections.

### 13.7.1 Longitudinal Analysis (CTBridge)

Perform a longitudinal analysis of the bridge under consideration using Caltrans CTBridge software. Results will determine:

- Axial load ( $A_x$ ) and longitudinal moment ( $M_z$ ) at top of the column for DC and DW
- Maximum unfactored axial load ( $A_x$ ) and associated longitudinal moment ( $M_z$ ) of design vehicular live loads for one lane per bent
- Maximum unfactored longitudinal moment ( $M_z$ ) and associated axial load ( $A_x$ ) of design vehicular live loads for the one lane per bent

### 13.7.2 Transverse Analysis (CSiBridge)

Perform a transverse analysis of bent cap (BDP Chapter 12, Bent-Cap) using commercial software CSiBridge. Results of the analysis is used to determine:

- Column axial load ( $P$ ) and transverse moment ( $M_3$ ) for DC and DW
- Maximum axial load ( $P$ ) and associated transverse moment ( $M_3$ ) for design vehicular live loads
- Maximum transverse moment ( $M_3$ ) and associated axial load ( $P$ ) for design vehicular live loads

*Note:* WinYIELD (Caltrans, 2008) uses the  $x$ -axis for longitudinal direction and  $y$ -axis for the transverse direction. The CTBridge output renames  $M_z$  as  $M_x$  and  $A_x$  as  $P$ . The CSiBridge output renames the transverse moment,  $M_3$ , as  $M_y$ .

### 13.7.3 Column Live Load Input Procedure

#### 13.7.3.1 Output from Longitudinal 2D Analysis (CTBridge)

Column unfactored live load forces and moments for one lane from longitudinal analysis (CTBridge) are summarized in Table 13.7-1 below:

**Table 13.7-1 Unfactored Bent Reactions for One Lane, Dynamic Load Allowance Factors Not Included**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated longitudinal moment			Maximum axial load and associated longitudinal moment	
	$A_x$ (kip)	$M_z$ (kip-ft)	$A_x$ (kip)	$M_z$ (kip-ft)
Truck	$(A_{\max}^T)_{CT}$	$((M_z^T)_{\text{assoc}})_{CT}$	$(A_{\max}^P)_{CT}$	$((M_z^P)_{\text{assoc}})_{CT}$
Lane	$(A_{\max}^L)_{CT}$	$((M_z^L)_{\text{assoc}})_{CT}$		
Maximum longitudinal moment and associated axial load			Maximum longitudinal moment and associated axial load	
	$A_x$ (kip)	$M_z$ (kip-ft)	$A_x$ (kip)	$M_z$ (kip-ft)
Truck	$(A_{\text{assoc}}^T)_{CT}$	$((M_z^T)_{\max})_{CT}$	$(A_{\text{assoc}}^P)_{CT}$	$((M_z^P)_{\max})_{CT}$
Lane	$(A_{\text{assoc}}^L)_{CT}$	$((M_z^L)_{\max})_{CT}$		

where:

$(A_{\max}^T)_{CT}$  = maximum axial force for truck load

$((M_z^T)_{\text{assoc}})_{CT}$  = longitudinal moment associated with maximum axial force for truck load

$(A_{\max}^L)_{CT}$  = maximum axial force for lane load

$((M_z^L)_{\text{assoc}})_{CT}$  = longitudinal moment associated with maximum axial force for lane load

$(A_{\max}^P)_{CT}$  = maximum axial force for permit vehicle load

$((M_z^P)_{\text{assoc}})_{CT}$  = longitudinal moment associated with maximum axial force for permit vehicle load

$((M_z^T)_{\max})_{CT}$  = maximum longitudinal moment for truck load

$(A_{\text{assoc}}^T)_{CT}$  = axial force associated with maximum longitudinal moment for truck load

$(M_z^L)_{\max}$  = maximum longitudinal moment for lane load

$(A_{\text{assoc}}^L)_{CT}$  = axial force associated with maximum longitudinal moment for lane load

$((M_z^P)_{\max})_{CT}$  = maximum longitudinal moment for permit vehicle load

$(A_{\text{assoc}}^P)_{CT}$  = axial force associated with maximum longitudinal moment for permit vehicle load

### 13.7.3.2 Output from 2D Transverse Analysis (CSiBridge)

Axial forces presented in Table 13.7-1 are converted to two pseudo wheel loads including dynamic allowance factor to be used in transverse analysis (see BDP Chapter 12) to be used in transverse analysis.

- Include dynamic load allowance factor for Table 13.7-1.
- Column reaction = 1.33(reaction/2) for truck  
= 1(reaction/2) for lane  
= 1.25(reaction/2) for P-15

The transverse analysis column forces for pseudo truck and permit wheel loadings are presented in Table 13.7-2.

**Table 13.7-2 Unfactored Column Reaction, Including Dynamic Load Allowance Factors**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated transverse moment			Maximum axial load and associated transverse moment	
	$P$ (kip)	$M_3$ (kip-ft)	$P$ (kip)	$M_3$ (kip-ft)
Truck	$(P_{\max}^T)_{CSi}$	$((M_3^T)_{\text{assoc}})_{CSi}$	$(P_{\max}^P)_{CSi}$	$((M_3^P)_{\text{assoc}})_{CSi}$
Maximum transverse moment and associated axial load			Maximum transverse moment and associated axial load	
	$P$ (kip)	$M_3$ (kip-ft)	$P$ (kip)	$M_3$ (kip-ft)
Truck	$(P_{\text{assoc}}^T)_{CSi}$	$((M_3^T)_{\max})_{CSi}$	$(P_{\text{assoc}}^P)_{CSi}$	$((M_3^P)_{\max})_{CSi}$

where:

$(P_{\max}^T)_{CSi}$  = maximum axial force due to pseudo truck wheel loads

$((M_3^T)_{\text{assoc}})_{CSi}$  = transverse moment associated with maximum axial force due to pseudo truck wheel loads.

$(P_{\max}^P)_{CSi}$  = maximum axial force due to pseudo permit wheel loads

$((M_3^P)_{\text{assoc}})_{CSi}$  = transverse moment associated with maximum axial force due to pseudo permit wheel loads

$((M_3^T)_{\max})_{CSi}$  = maximum transverse moment due to pseudo truck wheel loads

$(P_{\text{assoc}}^T)_{CSi}$  = axial force associated with maximum transverse moment due to pseudo truck wheel loads

$\left( (M_3^P)_{\max} \right)_{CSi}$  = maximum transverse moment due to pseudo permit wheel loads

$\left( P_{assoc}^P \right)_{CSi}$  = axial force associated with maximum transverse moment due to pseudo permit wheel loads

### 13.7.3.3 CTBridge output including Dynamic Load Allowance Factors

Multiply dynamic allowance factor for values in Table 13.7-1 divided by number of bent columns to get reactions per column (Table 13.7-3).

**Table 13.7-3 Unfactored Column Reactions for One Lane, Including Dynamic Load Allowance Factors**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated longitudinal moment			Maximum axial load and associated longitudinal moment	
	$P$ (kip)	$M_x$ (kip-ft)	$P$ (kip)	$M_x$ (kip-ft)
Truck	$\left( P_{\max}^T \right)_{CT}$	$\left( (M_x^T)_{assoc} \right)_{CT}$	$\left( P_{\max}^P \right)_{CT}$	$\left( (M_x^P)_{assoc} \right)_{CT}$
Lane	$\left( P_{\max}^L \right)_{CT}$	$\left( (M_x^L)_{assoc} \right)_{CT}$		
Maximum longitudinal moment and associated axial load			Maximum longitudinal moment and associated axial load	
	$P$ (kip)	$M_x$ (kip-ft)	$P$ (kip)	$M_x$ (kip-ft)
Truck	$\left( P_{assoc}^T \right)_{CT}$	$\left( (M_x^T)_{\max} \right)_{CT}$	$\left( P_{assoc}^P \right)_{CT}$	$\left( (M_x^P)_{\max} \right)_{CT}$
Lane	$\left( P_{assoc}^L \right)_{CT}$	$\left( (M_x^L)_{\max} \right)_{CT}$		

### 13.7.3.4 Truck and Lane Loads for Transverse Analysis (CSiBridge)

Split truck reactions results of transverse analysis (Table 13.7-3) into truck and lane loads as follows:

$$\text{Ratio of truck load per design vehicle} = \left[ \frac{\left( P_{\max}^T \right)_{CT}}{\left( P_{\max}^T \right)_{CT} + \left( P_{\max}^L \right)_{CT}} \right] = R1$$

$$\text{Ratio of lane load per design vehicle} = \left[ \frac{\left( P_{\max}^L \right)_{CT}}{\left( P_{\max}^T \right)_{CT} + \left( P_{\max}^L \right)_{CT}} \right] = R2$$

Unfactored column reactions (Table 13.7-4) including dynamic load allowance (CSiBridge):

$R1$  = truck load ratio of design vehicle (values of Table 13.7-2)

$R2$  = lane load ratio of design vehicle (values of Table 13.7-2)

**Table 13.7-4 Unfactored Column Reactions, Including Dynamic Load Allowance Factors**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated transverse moment			Maximum axial load and associated transverse moment	
	$P$ (kip)	$M_y$ (kip-ft)	$P$ (kip)	$M_y$ (kip-ft)
Truck	$(P_{\max}^T)_{CSi}$	$((M_y^T)_{\text{assoc}})_{CSi}$	$(P_{\max}^P)_{CSi}$	$((M_y^P)_{\text{assoc}})_{CSi}$
Lane	$(P_{\max}^L)_{CSi}$	$((M_y^L)_{\text{assoc}})_{CSi}$		
Maximum transverse moment and associated axial load			Maximum transverse moment and associated axial load	
	$P$ (kip)	$M_y$ (kip-ft)	$P$ (kip)	$M_y$ (kip-ft)
Truck	$(P_{\text{assoc}}^T)_{CSi}$	$((M_y^T)_{\max})_{CSi}$	$(P_{\text{assoc}}^P)_{CSi}$	$((M_y^P)_{\max})_{CSi}$
Lane	$(P_{\text{assoc}}^L)_{CSi}$	$((M_y^L)_{\max})_{CSi}$		

### 13.7.3.5 Combination of Longitudinal and Transverse Output

Combine forces and moments of Tables 13.7-3 and 13.7-4.

- Case 1: Maximum  $M_y$  (Table 13.7-5)
- Case 2: Maximum  $M_x$  (Table 13.7-6)
- Case 3: Maximum  $P$  (Table 13.7-7)

**Table 13.7-5 Case 1: Maximum Transverse Moment ( $M_y$ )**

	P-truck	H-truck	Lane
$M_y$ (kip-ft)	$((M_y^P)_{\max})_{CSi}$	$((M_y^T)_{\max})_{CSi}$	$((M_y^L)_{\max})_{CSi}$
$M_x$ (kip-ft)	$\left[ \frac{(P_{\text{assoc}}^P)_{CSi}}{(P_{\max}^P)_{CT}} \right] ((M_x^P)_{\text{assoc}})_{CT}$	$\left[ \frac{(P_{\text{assoc}}^T)_{CSi}}{(P_{\max}^T)_{CT}} \right] ((M_x^T)_{\text{assoc}})_{CT}$	$\left[ \frac{(P_{\text{assoc}}^L)_{CSi}}{(P_{\max}^L)_{CT}} \right] ((M_x^L)_{\text{assoc}})_{CT}$
$P$ (kip)	$(P_{\text{assoc}}^P)_{CSi}$	$(P_{\text{assoc}}^T)_{CSi}$	$(P_{\text{assoc}}^L)_{CSi}$

**Table 13.7-6 Case 2: Maximum Longitudinal Moment ( $M_x$ )**

	P-truck	H-truck	Lane
$M_y$ (kip-ft)	$\left[ \frac{(P_{assoc.}^P)_{CT}}{(P_{max}^P)_{CT}} \right] \left( (M_y^P)_{assoc.} \right)_{CSi}$	$\left[ \frac{(P_{assoc.}^T)_{CT}}{(P_{max}^T)_{CT}} \right] \left( (M_y^T)_{assoc.} \right)_{CSi}$	$\left[ \frac{(P_{assoc.}^L)_{CT}}{(P_{max}^L)_{CT}} \right] \left( (M_y^L)_{assoc.} \right)_{CSi}$
$M_x$ (kip-ft)	$\left[ \frac{(P_{max}^P)_{CSi}}{(P_{max}^P)_{CT}} \right] \left( (M_x^P)_{max} \right)_{CT}$	$\left[ \frac{(P_{max}^T)_{CSi}}{(P_{max}^T)_{CT}} \right] \left( (M_x^T)_{max} \right)_{CT}$	$\left[ \frac{(P_{max}^L)_{CSi}}{(P_{max}^L)_{CT}} \right] \left( (M_x^L)_{max} \right)_{CT}$
$P$ (kip)	$\left[ \frac{(P_{assoc.}^P)_{CT}}{(P_{max}^P)_{CT}} \right] (P_{max.}^P)_{CSi}$	$\left[ \frac{(P_{assoc.}^T)_{CT}}{(P_{max}^T)_{CT}} \right] (P_{max.}^T)_{CSi}$	$\left[ \frac{(P_{assoc.}^L)_{CT}}{(P_{max}^L)_{CT}} \right] (P_{max.}^L)_{CSi}$

**Table 13.7-7 Case 3: Maximum Axial Load ( $P$ )**

	P-truck	H-truck	Lane
$M_y$ (kip-ft)	$\left( (M_y^P)_{assoc.} \right)_{CSi}$	$\left( (M_y^T)_{assoc.} \right)_{CSi}$	$\left( (M_y^L)_{assoc.} \right)_{CSi}$
$M_x$ (kip-ft)	$\left[ \frac{(P_{max}^P)_{CSi}}{(P_{max}^P)_{CT}} \right] \left( (M_x^P)_{assoc.} \right)_{CT}$	$\left[ \frac{(P_{max}^T)_{CSi}}{(P_{max}^T)_{CT}} \right] \left( (M_x^T)_{assoc.} \right)_{CT}$	$\left[ \frac{(P_{max}^L)_{CSi}}{(P_{max}^L)_{CT}} \right] \left( (M_x^L)_{assoc.} \right)_{CT}$
$P$ (kip)	$(P_{max}^P)_{CSi}$	$(P_{max}^T)_{CSi}$	$(P_{max}^L)_{CSi}$

### 13.7.3.6 WinYIELD Live Load Input

Transfer Tables 13.7-5, 13.7-6, and 13.7-7 data into Table 13.7-8, which will be used as load input for the WinYIELD program.

**Table 13.7-8 Input for Column Live Load Analysis of WinYIELD Program.**

	Case 1: Max Transverse ( $M_y$ )			Case 2: Max Longitudinal ( $M_x$ )			Case 3: Max Axial ( $P$ )		
	P-truck	H-truck	Lane Load	P-truck	H-truck	Lane Load	P-truck	H-truck	Lane Load
$M_y$ Trans	<b>TABLE 13.7-5 Data</b>			<b>TABLE 13.7-6 Data</b>			<b>TABLE 13.7-7 Data</b>		
$M_x$ Long									
$P$ Axial									

**13.7.4 Wind Loads (WS, WL)**

Calculate wind moments and axial loads for column (see BDP Chapter 3).

**13.7.5 Braking Force (BR)**

Calculate braking force moments and axial load for column (see BDP Chapter 3).

**13.7.6 Prestress Shortening Effects (CR, SH)**

Calculate prestress shortening moments as shown in design example (13.10).

**13.7.7 Prestressing Secondary Effect Forces (PS)**

Calculate secondary prestress moments and axial loads (from CTBridge output).

**13.7.8 Input Loads into WinYIELD**

Transfer all loads into WinYIELD's load table.

**13.7.9 Column Design/Check**

Run WinYIELD to design/check the main vertical column reinforcement.

## 13.8 COLUMN SHEAR DESIGN PROCEDURE

Column shear demand values are calculated from longitudinal and transverse analyses.

### 13.8.1 Longitudinal Analysis

Perform a longitudinal analysis (CTBridge) to determine:

- Longitudinal shear ( $V_y$ ) and moment ( $M_z$ ) for DC and DW at top and bottom of the column.
- Maximum longitudinal shear ( $V_y$ ) and associated moment ( $M_z$ ) for design vehicular live loads at top and bottom of the bent unfactored reactions for one lane as shown in Table 13.8-1.

**Table 13.8-1 Longitudinal Unfactored Bent Reactions for One Lane, Dynamic Load Allowance Factors Not Included.**

Design Vehicle			Permit Vehicle	
Maximum longitudinal shear and associated longitudinal moment at top of the column			Maximum longitudinal shear and associated longitudinal moment at top of the column	
	$V_y$ (kip)	$M_z$ (kip-ft)	$V_y$ (kip)	$M_z$ (kip-ft)
Truck	$((V_y^T)_{max})_{CT}$	$((M_z^T)_{assoc})_{CT}$	$((V_y^P)_{max})_{CT}$	$((M_z^P)_{assoc})_{CT}$
Lane	$((V_y^L)_{max})_{CT}$	$((M_z^L)_{assoc})_{CT}$		
Maximum longitudinal shear and associated longitudinal moment at bottom of the column			Maximum longitudinal shear and associated longitudinal moment at bottom of the column	
	$V_y$ (kip)	$M_z$ (kip-ft)	$V_y$ (kip)	$M_z$ (kip-ft)
Truck	$((V_y^T)_{max})_{CT}$	$((M_z^T)_{assoc})_{CT}$	$((V_y^P)_{max})_{CT}$	$((M_z^P)_{assoc})_{CT}$
Lane	$((V_y^L)_{max})_{CT}$	$((M_z^L)_{assoc})_{CT}$		

where:

$((V_y^T)_{max})_{CT}$  = maximum longitudinal shear at top and bottom of column for truck load

$((M_z^T)_{assoc})_{CT}$  = longitudinal moment at top and bottom of column associated with maximum shear for truck load

$((V_y^L)_{max})_{CT}$  = maximum longitudinal shear at top and bottom of column for lane load

$((M_z^L)_{assoc})_{CT}$  = longitudinal moment at top and bottom of column associated with maximum shear for lane load

$((V_y^P)_{max})_{CT}$  = maximum longitudinal shear at top and bottom of column for permit load

$((M_z^P)_{assoc})_{CT}$  = longitudinal moment at top and bottom of column associated with maximum shear for permit load

## 13.8.2 Transverse Analysis

Perform a transverse analysis (CSiBridge) to determine:

- Column transverse shears ( $V_2$ ) and associated moment ( $M_3$ ) for DC and DW
- Maximum transverse shear ( $V_2$ ) and associated moment ( $M_3$ ) for design vehicular live loads at top and bottom of the column with dynamic load allowance factors included, as shown in Table 13.8-2

**Table 13.8-2 Transverse Unfactored Column Reactions Including Dynamic Load Allowance Factors**

Design Vehicle			Permit Vehicle	
Maximum transverse shear and associated transverse moment at top of the column			Maximum transverse shear and associated transverse moment at top of the column	
	$V_2$ (kip)	$M_3$ (kip-ft)	$V_2$ (kip)	$M_3$ (kip-ft)
Truck	$((V_2^T)_{max})_{CSi}$	$((M_3^T)_{assoc})_{CSi}$	$((V_2^P)_{max})_{CSi}$	$((M_3^P)_{assoc})_{CSi}$
Maximum transverse shear and associated transverse moment at bottom of the column			Maximum transverse shear and associated transverse moment at bottom of the column	
	$V_2$ (kip)	$M_3$ (kip-ft)	$V_2$ (kip)	$M_3$ (kip-ft)
Truck	$((V_2^T)_{max})_{CSi}$	$((M_3^T)_{assoc})_{CSi}$	$((V_2^P)_{max})_{CSi}$	$((M_3^P)_{assoc})_{CSi}$

where:

$((V_2^T)_{max})_{CSi}$  = maximum longitudinal shear at top and bottom of column for truck load

$((M_3^T)_{assoc})_{CSi}$  = transverse moment at top and bottom of column associated with maximum shear for truck load

$((V_2^P)_{max})_{CSi}$  = maximum transverse shear at top and bottom of column for permit load

$((M_3^P)_{assoc})_{CSi}$  = transverse moment at top and bottom of column associated with maximum shear for permit load

## 13.8.3 Column Live Load Input Procedure

### 13.8.3.1 Output from Longitudinal 2D Analysis (CTBridge)

Include dynamic load allowance factors per column for CTBridge output (Table 13.8-1) and summarize the results in Table 13.8-3.

**Table 13.8-3 Unfactored Column Longitudinal Shear and Associated Longitudinal Moment for One Lane, Including Dynamic Load Allowance Factors (CTBridge)**

Design Vehicle			Permit Vehicle	
Maximum longitudinal shear and associated longitudinal moment at top of the column			Maximum longitudinal shear and associated longitudinal moment at top of the column	
	$V_y$ (kip)	$M_z$ (kip-ft)	$V_y$ (kip)	$M_z$ (kip-ft)
Truck	$((V_y^T)_{max})_{CT}$	$((M_z^T)_{assoc})_{CT}$	$((V_y^P)_{max})_{CT}$	$((M_z^P)_{assoc})_{CT}$
Lane	$((V_y^L)_{max})_{CT}$	$((M_z^L)_{assoc})_{CT}$		
Maximum longitudinal shear and associated longitudinal moment at bottom of the column			Maximum longitudinal shear and associated longitudinal moment at bottom of the column	
	$V_y$ (kip)	$M_z$ (kip-ft)	$V_y$ (kip)	$M_z$ (kip-ft)
Truck	$((V_y^T)_{max})_{CT}$	$((M_z^T)_{assoc})_{CT}$	$((V_y^P)_{max})_{CT}$	$((M_z^P)_{assoc})_{CT}$
Lane	$((V_y^L)_{max})_{CT}$	$((M_z^L)_{assoc})_{CT}$		

### 13.8.3.2 Output from 2D Transverse Analysis (CSiBridge)

Reform Table 13.8-2 to split truck reactions of CSiBridge analysis (Table 13.8-2) into truck and lane loads (13.7.3.4) as shown in Table 13.8-4.

**Table 13.8-4 Unfactored Column Reactions, Including Dynamic Load Allowance Factors (CSiBridge)**

Design Vehicle			Permit Vehicle	
Maximum transverse shear and associated longitudinal moment at top of the column			Maximum transverse shear and associated longitudinal moment at top of the column	
	$V_2$ (kip)	$M_3$ (kip-ft)	$V_2$ (kip)	$M_3$ (kip-ft)
Truck	$((V_2^T)_{max})_{CSi}$	$((M_3^T)_{assoc})_{CSi}$	$((V_2^P)_{max})_{CSi}$	$((M_3^P)_{assoc})_{CSi}$
Lane	$((V_2^L)_{max})_{CSi}$	$((M_3^L)_{assoc})_{CSi}$		
Maximum transverse shear and associated longitudinal moment at bottom of the column			Maximum transverse shear and associated longitudinal moment at bottom of the column	
	$V_2$ (kip)	$M_3$ (kip-ft)	$V_2$ (kip)	$M_3$ (kip-ft)
Truck	$((V_2^T)_{max})_{CSi}$	$((M_3^T)_{assoc})_{CSi}$	$((V_2^P)_{max})_{CSi}$	$((M_3^P)_{assoc})_{SAP}$
Lane	$((V_2^L)_{max})_{CSi}$	$((M_3^L)_{assoc})_{CSi}$		

Since the longitudinal shears and associated longitudinal moments are per one lane from CTBridge, the total longitudinal shears and associated longitudinal moments should be calculated as shown in Table 13.8-5.

**Table 13.8-5 Total Longitudinal Shear ( $V_y$ ) and Associated Longitudinal Moment ( $M_z$ )**

	P-truck	H-truck	Lane
$(V_y)_{max}$ (kip)	$\left[ \frac{\left( \frac{P_{max}^P}{P_{max}^P} \right)_{CSi}}{\left( \frac{P_{max}^P}{P_{max}^P} \right)_{CT}} \right] \left( (V_y^P)_{max} \right)_{CT}$	$\left[ \frac{\left( \frac{P_{max}^T}{P_{max}^T} \right)_{CSi}}{\left( \frac{P_{max}^T}{P_{max}^T} \right)_{CT}} \right] \left( (V_y^T)_{max} \right)_{CT}$	$\left[ \frac{\left( \frac{P_{max}^L}{P_{max}^L} \right)_{CSi}}{\left( \frac{P_{max}^L}{P_{max}^L} \right)_{CT}} \right] \left( (V_y^L)_{max} \right)_{CT}$
$(M_z)_{assoc.}$ (kip-ft)	$\left[ \frac{\left( \frac{P_{max}^P}{P_{max}^P} \right)_{CSi}}{\left( \frac{P_{max}^P}{P_{max}^P} \right)_{CT}} \right] \left( (M_z^P)_{assoc} \right)_{CT}$	$\left[ \frac{\left( \frac{P_{max}^T}{P_{max}^T} \right)_{CSi}}{\left( \frac{P_{max}^T}{P_{max}^T} \right)_{CT}} \right] \left( (M_z^T)_{assoc} \right)_{CT}$	$\left[ \frac{\left( \frac{P_{max}^L}{P_{max}^L} \right)_{CSi}}{\left( \frac{P_{max}^L}{P_{max}^L} \right)_{CT}} \right] \left( (M_z^L)_{assoc} \right)_{CT}$

- Determine factored shear and associated factored moment for Strength I and Strength II Limit States.
- Design for shear for controlling case as per AASHTO 5.8.3.
- The following example in Section 13.10 will demonstrate the shear design in details.

## 13.9 COLUMN SEISMIC DESIGN PROCEDURE

Column seismic design and details shall follow the *Caltrans Seismic Design Criteria* 1.7.

## 13.10 DESIGN EXAMPLE

The bridge shown in Figures 13.10-1 and 13.10-2 are a three-span PS/CIP box girder bridge with 20° skew and two column bents. The superstructure depth is 6.75 ft. Columns' heights from top of footing to superstructure soffit are 44 ft at bent two and 47 ft at bent three. The columns are round with a diameter of 6 ft. The centerline distance between columns is 34 ft.

### 13.10.1 Design Column One at Bent Two

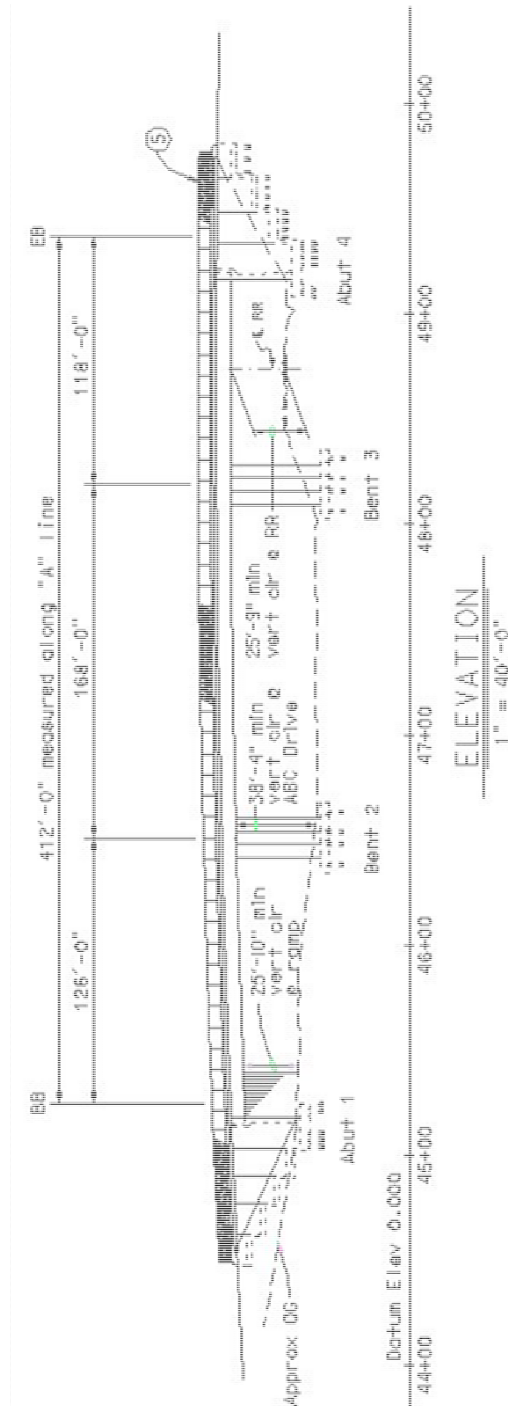


Figure 13.10-1 Elevation View of Example Bridge.



## 13.10.2 Flexural Check of Main Column Reinforcement ( $A_s$ )

### 13.10.2.1 Longitudinal Analysis

From CTBridge output, determine  $M_z$  for Dead Load (DC) and Added Dead Load (DW).

**Table 13.10-1 Dead Load Unfactored Column Forces**

### Dead Load - Unfactored Column Forces - Final

Bent 2, Column 1						
Location	AX	VY	VZ	TX	MY	MZ
ft	kip	kip	kip	kip-ft	kip-ft	kip-ft
0.00	-1501.8	21.0	1.1	0.0	0.0	-0.0
11.00	-1455.2	21.0	1.1	0.0	12.6	-231.3
22.00	-1408.5	21.0	1.1	0.0	25.1	-462.6
33.00	-1361.9	21.0	1.1	-0.0	37.7	-693.9
44.00	-1315.2	21.0	1.1	-0.0	50.3	-925.2

**Table 13.10-2 Additional Dead Load Unfactored Column Forces.**

### Additional Dead Load - Unfactored Column Forces

Bent 2, Column 1						
Location	AX	VY	VZ	TX	MY	MZ
ft	kip	kip	kip	kip-ft	kip-ft	kip-ft
0.00	-161.1	2.5	0.1	0.0	0.0	-0.0
11.00	-161.1	2.5	0.1	0.0	1.6	-27.5
22.00	-161.1	2.5	0.1	0.0	3.2	-55.1
33.00	-161.1	2.5	0.1	-0.0	4.7	-82.6
44.00	-161.1	2.5	0.1	-0.0	6.3	-110.1

Controlling moments,  $M_z$ , are as follows:

$$\text{DC } M_z = -925.2 \text{ kip-ft}$$

$$\text{DW } M_z = -110.1 \text{ kip-ft}$$

### 13.10.2.2 Design Vehicular Live Loads

From CTBridge output, determine bent two unfactored reactions for one lane (no dynamic load allowance factors) for the design vehicle as:

- Maximum  $A_x$  and associated  $M_z$  at top of the column
- Maximum  $M_z$  and associated  $A_x$  at top of the column

**Table 13.10-3 Live Load, Controlling Unfactored Bent Reactions**

## Live Load - Controlling Unfactored Bent Reactions

### Bent 2 Reactions - LRFD Design Vehicle

#### No Dynamic Load Allowance - Single Lane

Location	Primary DOF	T / L	AX kip	VY kip	VZ kip	MY kip·ft	MZ kip·ft
Col Tops	AX-	Truck	-114.58	1.48	0.22	9.85	-64.97
		Lane	-99.21	3.80	0.67	29.52	-167.13
Col Tops	AX+	Truck	8.00	-4.96	-1.25	-54.81	218.37
		Lane	4.19	-2.60	-0.66	-28.87	114.57
Col Tops	MY-	Truck	8.00	-4.96	-1.25	-54.81	218.37
		Lane	-38.72	0.81	-0.91	-39.87	-35.81
Col Tops	MY+	Truck	-65.14	0.50	1.39	61.05	-22.14
		Lane	-60.59	0.72	0.90	39.42	-31.78
Col Tops	MZ-	Truck	-58.56	10.34	0.19	8.44	-454.77
		Lane	-59.85	7.64	0.15	6.48	-336.13
Col Tops	MZ+	Truck	-44.34	-7.55	-0.11	-4.99	332.16
		Lane	-41.57	-5.42	-0.05	-2.29	238.51
Col Tops	VY-	Truck	-44.34	-7.55	-0.11	-4.99	332.16
		Lane	-41.57	-5.42	-0.05	-2.29	238.51

From the CTBridge output, determine unfactored bent two reactions for one lane (no dynamic load allowance factors) of permit vehicle load as follows:

- Maximum  $A_x$  and associated  $M_z$  at top of the column
- Maximum  $M_z$  and associated  $A_x$  at top of the column

**Table 13.10-4 Bent 2 Reactions, LRFD Permit Vehicle**

<b>Bent 2 Reactions - LRFD Permit Vehicle</b>							
<b>No Dynamic Load Allowance - Single Lane</b>							
<b>Location</b>	<b>Primary DOF</b>	<b>T / L</b>	<b>AX kip</b>	<b>VY kip</b>	<b>VZ kip</b>	<b>MY kip-ft</b>	<b>MZ kip-ft</b>
Col Tops	AX-	Truck	-360.23	4.57	0.56	24.69	-201.20
Col Tops	AX+	Truck	19.75	-12.28	-3.09	-136.17	540.25
Col Tops	MY-	Truck	19.75	-12.28	-3.09	-136.17	540.25
Col Tops	MY+	Truck	-235.51	-16.19	2.83	124.67	712.36
Col Tops	MZ-	Truck	-231.37	33.78	0.58	25.31	-1486.10
Col Tops	MZ+	Truck	-235.51	-16.19	2.83	124.67	712.36
Col Tops	VY-	Truck	-235.51	-16.19	2.83	124.67	712.36
Col Tops	VY+	Truck	-231.37	33.78	0.58	25.31	-1486.10
Col Tops	VZ-	Truck	19.75	-12.28	-3.09	-136.17	540.25
Col Tops	VZ+	Truck	-235.51	-16.19	2.83	124.67	712.36

### 13.10.2.3 Transverse Analysis

From CSiBridge output, determine the axial loads and transverse moments for DC and DW.

**Table 13.10-5 Axial loads and Transverse Moment for Dead Load and Added Dead Load**

<b>TABLE: Element Forces - Frames</b>												
<b>Frame</b>	<b>Station</b>	<b>OutputCase</b>	<b>CaseType</b>	<b>StepType</b>	<b>P</b>	<b>V2</b>	<b>V3</b>	<b>T</b>	<b>M2</b>	<b>M3</b>	<b>FrameElem</b>	<b>ElemStation</b>
<b>Text</b>	<b>ft</b>	<b>Text</b>	<b>Text</b>	<b>Text</b>	<b>Kip</b>	<b>Kip</b>	<b>Kip</b>	<b>Kip-ft</b>	<b>Kip-ft</b>	<b>Kip-ft</b>	<b>Text</b>	<b>ft</b>
1	0	DEAD	LinStatic		-2785.814	-10.497	0	0	0	0	0 1-1	
1	4.8894	DEAD	LinStatic		-2785.814	-10.497	0	0	0	51.3239	1-1	4.889
1	9.7789	DEAD	LinStatic		-2785.814	-10.497	0	0	0	102.6478	1-1	9.778
1	14.6683	DEAD	LinStatic		-2785.814	-10.497	0	0	0	153.9717	1-1	14.668
1	19.5578	DEAD	LinStatic		-2785.814	-10.497	0	0	0	205.2956	1-1	19.557
1	24.4472	DEAD	LinStatic		-2785.814	-10.497	0	0	0	256.6195	1-1	24.447
1	29.3367	DEAD	LinStatic		-2785.814	-10.497	0	0	0	307.9435	1-1	29.336
1	34.2261	DEAD	LinStatic		-2785.814	-10.497	0	0	0	359.2674	1-1	34.226
1	39.1156	DEAD	LinStatic		-2785.814	-10.497	0	0	0	410.5913	1-1	39.115
1	44.005	DEAD	LinStatic		-2785.814	-10.497	0	0	0	461.9152	1-1	44.00
1	0	ADL	LinStatic		-162.5	-0.523	0	0	0	-3.553E-15	1-1	
1	4.8894	ADL	LinStatic		-162.5	-0.523	0	0	0	2.5561	1-1	4.889
1	9.7789	ADL	LinStatic		-162.5	-0.523	0	0	0	5.1122	1-1	9.778
1	14.6683	ADL	LinStatic		-162.5	-0.523	0	0	0	7.6682	1-1	14.668
1	19.5578	ADL	LinStatic		-162.5	-0.523	0	0	0	10.2243	1-1	19.557
1	24.4472	ADL	LinStatic		-162.5	-0.523	0	0	0	12.7804	1-1	24.447
1	29.3367	ADL	LinStatic		-162.5	-0.523	0	0	0	15.3365	1-1	29.336
1	34.2261	ADL	LinStatic		-162.5	-0.523	0	0	0	17.8926	1-1	34.226
1	39.1156	ADL	LinStatic		-162.5	-0.523	0	0	0	20.4486	1-1	39.115
1	44.005	ADL	LinStatic		-162.5	-0.523	0	0	0	23.0047	1-1	44.00

### 13.10.2.4 Live Loads

From CSiBridge output, determine the unfactored column reactions for design vehicle including the dynamic load allowance factors which are:

- Maximum  $P$  and associated  $M_3$
- Maximum  $M_3$  and associated  $P$

**Table 13.10-6 Maximum Axial Load ( $P$ ) for Design Vehicle**

TABLE: Element Forces - Frames												
Frame	Station	OutputCase	CaseType	StepType	P	V2	V3	T	M2	M3	FrameElem	ElemStation
Text	ft	Text	Text	Text	Kip	Kip	Kip	Kip-ft	Kip-ft	Kip-ft	Text	ft
1	4.8894	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-23.5791	1-1	4.889
1	9.7789	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-47.1582	1-1	9.778
1	14.6683	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-70.7373	1-1	14.668
1	19.5578	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-94.3163	1-1	19.557
1	24.4472	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-117.8954	1-1	24.447
1	29.3367	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-141.4745	1-1	29.336
1	34.2261	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-165.0536	1-1	34.226
1	39.1156	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-188.6327	1-1	39.115
1	44.005	DESIGN	LinMoving	Max P	66.276	4.822	0	0	0	-212.2118	1-1	44.00
1	0	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	0	1-1	
1	4.8894	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	10.923	1-1	4.889
1	9.7789	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	21.8461	1-1	9.778
1	14.6683	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	32.7691	1-1	14.668
1	19.5578	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	43.6922	1-1	19.557
1	24.4472	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	54.6152	1-1	24.447
1	29.3367	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	65.5382	1-1	29.336
1	34.2261	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	76.4613	1-1	34.226
1	39.1156	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	87.3843	1-1	39.115
1	44.005	DESIGN	LinMoving	Min P	-568.606	-2.234	0	0	0	98.3074	1-1	44.00

**Table 13.10-7 Maximum Longitudinal Moment ( $M_3$ ) for Design Vehicle**

TABLE: Element Forces - Frames												
Frame	Station	OutputCase	CaseType	StepType	P	V2	V3	T	M2	M3	FrameElem	ElemStation
Text	ft	Text	Text	Text	Kip	Kip	Kip	Kip-ft	Kip-ft	Kip-ft	Text	ft
1	0	DESIGN	LinMoving	Max M3	0	0	0	0	0	0	1-1	
1	4.8894	DESIGN	LinMoving	Max M3	-29.028	-1.011	0	0	0	44.4949	1-1	4.889
1	9.7789	DESIGN	LinMoving	Max M3	-58.057	-2.022	0	0	0	88.9898	1-1	9.778
1	14.6683	DESIGN	LinMoving	Max M3	-87.085	-3.033	0	0	0	133.4847	1-1	14.668
1	19.5578	DESIGN	LinMoving	Max M3	-116.113	-4.045	0	0	0	177.9796	1-1	19.557
1	24.4472	DESIGN	LinMoving	Max M3	-145.142	-5.056	0	0	0	222.4745	1-1	24.447
1	29.3367	DESIGN	LinMoving	Max M3	-174.17	-6.067	0	0	0	266.9693	1-1	29.336
1	34.2261	DESIGN	LinMoving	Max M3	-203.198	-7.078	0	0	0	311.4642	1-1	34.226
1	39.1156	DESIGN	LinMoving	Max M3	-232.227	-8.089	0	0	0	355.9591	1-1	39.115
1	44.005	DESIGN	LinMoving	Max M3	-261.255	-9.1	0	0	0	400.454	1-1	44.00

From CSiBridge output, determine the unfactored column reactions for permit vehicle including the dynamic load allowance factors which are:

- Maximum  $P$  and associated  $M_3$
- Maximum  $M_3$  and associated  $P$

**Table 13.10-8 Maximum Axial Load ( $P$ ) for Permit Vehicle.**

TABLE: Element Forces - Frames												
Frame Text	Station ft	OutputCase Text	CaseType Text	StepType Text	P Kip	V2 Kip	V3 Kip	T Kip-ft	M2 Kip-ft	M3 Kip-ft	FrameElem Text	ElemStation ft
1	4.8894	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-42.2926	1-1	4.889
1	9.7789	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-84.5853	1-1	9.778
1	14.6683	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-126.8779	1-1	14.668
1	19.5578	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-169.1706	1-1	19.557
1	24.4472	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-211.4632	1-1	24.447
1	29.3367	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-253.7559	1-1	29.336
1	34.2261	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-296.0485	1-1	34.226
1	39.1156	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-338.3412	1-1	39.115
1	44.005	PERMITT	LinMoving	Max P	118.876	8.65	0	0	0	-380.6338	1-1	44.005
1	0	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	0	1-1	
1	4.8894	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-21.4083	1-1	4.889
1	9.7789	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-42.8166	1-1	9.778
1	14.6683	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-64.2249	1-1	14.668
1	19.5578	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-85.6332	1-1	19.557
1	24.4472	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-107.0415	1-1	24.447
1	29.3367	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-128.4497	1-1	29.336
1	34.2261	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-149.858	1-1	34.226
1	39.1156	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-171.2663	1-1	39.115
1	44.005	PERMITT	LinMoving	Min P	-960.544	4.378	0	0	0	-192.6746	1-1	44.005

**Table 13.10-9 Maximum Longitudinal Moment ( $M_3$ ) for Permit Vehicle.**

TABLE: Element Forces - Frames												
Frame Text	Station ft	OutputCase Text	CaseType Text	StepType Text	P Kip	V2 Kip	V3 Kip	T Kip-ft	M2 Kip-ft	M3 Kip-ft	FrameElem Text	ElemStation ft
1	39.1156	PERMITT	LinMoving	Max M2	0	0	0	0	0	0	1-1	39.115
1	44.005	PERMITT	LinMoving	Max M2	0	0	0	0	0	0	1-1	44.005
1	0	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	
1	4.8894	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	4.889
1	9.7789	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	9.778
1	14.6683	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	14.668
1	19.5578	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	19.557
1	24.4472	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	24.447
1	29.3367	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	29.336
1	34.2261	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	34.226
1	39.1156	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	39.115
1	44.005	PERMITT	LinMoving	Min M2	0	0	0	0	0	0	1-1	44.005
1	0	PERMITT	LinMoving	Max M3	0	0	0	0	0	0	1-1	
1	4.8894	PERMITT	LinMoving	Max M3	-52.067	-1.814	0	0	0	79.8083	1-1	4.889
1	9.7789	PERMITT	LinMoving	Max M3	-104.133	-3.627	0	0	0	159.6166	1-1	9.778
1	14.6683	PERMITT	LinMoving	Max M3	-156.2	-5.441	0	0	0	239.4249	1-1	14.668
1	19.5578	PERMITT	LinMoving	Max M3	-208.267	-7.254	0	0	0	319.2332	1-1	19.557
1	24.4472	PERMITT	LinMoving	Max M3	-260.334	-9.068	0	0	0	399.0415	1-1	24.447
1	29.3367	PERMITT	LinMoving	Max M3	-312.4	-10.882	0	0	0	478.8498	1-1	29.336
1	34.2261	PERMITT	LinMoving	Max M3	-364.467	-12.695	0	0	0	558.6581	1-1	34.226
1	39.1156	PERMITT	LinMoving	Max M3	-416.534	-14.509	0	0	0	638.4664	1-1	39.115
1	44.005	PERMITT	LinMoving	Max M3	-468.601	-16.323	0	0	0	718.2747	1-1	44.005
1	0	PERMITT	LinMoving	Min M3	0	0	0	0	0	0	1-1	

### 13.10.2.5 Output from Longitudinal 2D Analysis (CTBridge)

Column unfactored live load forces and moments for one lane from longitudinal analysis (CTBridge) are presented in Table 13.10-10.

**Table 13.10-10 Unfactored Bent Reactions for One Lane, Dynamic Load Allowance Factors Not Included**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated longitudinal moment			Maximum axial load and associated longitudinal moment	
	$A_x$ (kip)	$M_z$ (kip-ft)	$A_x$ (kip)	$M_z$ (kip-ft)
Truck	-115	-65	-360	-201
Lane	-99	-167		
Maximum longitudinal moment and associated axial load			Maximum longitudinal moment and associated axial load	
	$A_x$ (kip)	$M_z$ (kip-ft)	$A_x$ (kip)	$M_z$ (kip-ft)
Truck	-44	332	-231	-1486
Lane	-42	239		

### 13.10.2.6 Output from Transverse 2D Analysis (CSiBridge)

Two pseudo wheel loads including dynamic allowance factor to be used in transverse analysis (see Section 13.7.3.2).

The transverse analysis column forces for pseudo truck and permit wheel loadings are presented in Table 13.10-11.

**Table 13.10-11 Unfactored Column Reaction, Including Dynamic Load Allowance Factors.**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated transverse moment			Maximum axial load and associated transverse moment	
	$P$ (kip)	$M_3$ (kip-ft)	$P$ (kip)	$M_3$ (kip-ft)
Truck	-569	98	-961	-193
Maximum transverse moment and associated axial load			Maximum transverse moment and associated axial load	
	$P$ (kip)	$M_3$ (kip-ft)	$P$ (kip)	$M_3$ (kip-ft)
Truck	-261	401	-469	718

### 13.10.2.7 Unfactored Column Reactions for One Lane, Including Impact (CTBridge)

Multiply dynamic allowance factor for values in Table 13.10-10 and calculate reaction per column (Table 13.10-12).

**Table 13.10-12 Unfactored Column Reactions for One Lane, Including Dynamic Load Allowance Factors (CTBridge)**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated longitudinal moment			Maximum axial load and associated longitudinal moment	
	$A_x$ (kip)	$M_z$ (kip-ft)	$A_x$ (kip)	$M_z$ (kip-ft)
Truck	-76	-43	-225	-126
Lane	-50	-84		
Maximum longitudinal moment and associated axial load			Maximum longitudinal moment and associated axial load	
	$A_x$ (kip)	$M_z$ (kip-ft)	$A_x$ (kip)	$M_z$ (kip-ft)
Truck	-29	221	-145	-929
Lane	-21	119		

### 13.10.2.8 Unfactored Column Reactions, Including Dynamic Load Allowance Factors (CSiBridge)

Split the truck reactions results of transverse analysis (Section 13.7.3.4) into truck and lane loads as follows:

$$\text{Ratio of truck load per design vehicle} = (76.2) / (76.2 + 49.605) = 0.606$$

$$\text{Ratio of lane load per design vehicle} = (49.6) / (76.2 + 49.605) = 0.394$$

$$\text{Truck load of design vehicle} = 0.606 \text{ (values of Table 13.10-11)}$$

$$\text{Lane load of design vehicle} = 0.394 \text{ (values of Table 13.10-11)}$$

Table 13.10-13 summarizes the truck and lane loads for both design and permit vehicles of transverse analysis.

**Table 13.10-13 Unfactored Column Reactions, Including Dynamic Load Allowance Factors (CSiBridge)**

Design Vehicle			Permit Vehicle	
Maximum axial load and associated transverse moment			Maximum axial load and associated transverse moment	
	$P$ (kip)	$M_3$ (kip-ft)	$P$ (kip)	$M_3$ (kip-ft)
Truck	-345	59	-961	-193
Lane	-224	39		
Maximum transverse moment and associated axial load			Maximum transverse moment and associated axial load	
	$P$ (kip)	$M_3$ (kip-ft)	$P$ (kip)	$M_3$ (kip-ft)
Truck	-158	243	-469	718
Lane	-103	158		

Combine load results as shown in Tables 13.7-5, 13.7-6, 13.7-7, and 13.7-8 to get WinYEILD input loads as shown in Table 13.10-14.

**Table 13.10-14 WinYIELD Column Live Load Input**

	Case 1 Max Transverse- $M_y$			Case 2 Max Longitudinal- $M_x$			Case 3 Max Axial- $P$		
	P-Truck	H-Truck	Lane Load	P-Truck	H-Truck	Lane Load	P-Truck	H-Truck	Lane Load
$M_{y-Trans}$ (kip-ft)	718	243	158	-124	23	16	-193	60	39
$M_{x-Long}$ (kip-ft)	-262	-90	-173	-3965	1003	533	-537	-195	-377
$P-Axial$ (kip)	-469	-158	-103	-617	-132	-95	-961	-345	-224

### 13.10.2.9 Wind Load (WS, WL)

- Wind on structure (WS):

Average bridge height = 50.25 ft

Assume bridge is in “Open Country,” from AASHTO Table 3.8.1.1-1

$V_o = 8.2$  mph

$Z_o = 0.23$  ft

$$V_{DZ} = (2.5)V_o \left[ \frac{V_{30}}{V_B} \right] \ln \left[ \frac{Z}{Z_o} \right] \quad (\text{AASHTO 3.8.1.1-1})$$

$$V_{DZ} = (2.5)(8.2) \left[ \frac{100}{100} \right] \ln \left[ \frac{50.25}{0.23} \right] = 110.4 \text{ mph (design wind velocity)}$$

$$P_D = P_B \left[ \frac{V_{DZ}}{V_B} \right]^2 \text{ for wind skew direction} = 0^\circ \quad (\text{AASHTO 3.8.1.2.1-1})$$

From AASHTO Table 3.8.1.2.1-1

$P_B = 0.05$  for superstructure (skew angle of wind =  $0^\circ$ )

$P_B = 0.04$  for columns (skew angle of wind =  $0^\circ$ )

$$P_D = 0.05 \left[ \frac{110.4}{100} \right]^2 = 0.061 \text{ ksf} \quad (\text{Superstructure})$$

$$P_D = 0.04 \left[ \frac{110.4}{100} \right]^2 = 0.049 \text{ ksf} \quad (\text{Columns})$$

The base wind pressure,  $P_B$ , for various angles of wind directions may be taken as specified in AASHTO Table 3.8.1.2.2-1 (AASHTO, 2012).

where:

$P_B$  = base wind pressure, corresponding to  $V_B=100$  mph

$P_D$  = wind pressure on structures, LRFD equation 3.8.1.2.1-1

$V_{DZ}$  = design wind velocity (mph) at design elevations

$V_B$  = base wind velocity of 100 mph at 30 ft height

$V_o$  = friction velocity (mph), LRFD Table 3.8.1.1-1

$Z$  = height of structure (ft) at which wind loads are being calculated as measured from low ground, or from water level, > 30 ft

$Z_o$  = friction length (ft) upstream fetch, LRFD Table 3.8.1.1-1

The wind pressure,  $P_D$ , is calculated at various angles using the base wind pressure,  $P_B$ , as per AASHTO Table 3.8.1.2.2-1. Table 13.10-15 lists the wind pressure,  $P_D$ , at various angles of wind.

**Table 13.10-15 Wind Pressure at Various Skew Angles of Wind**

Skew angle of wind (degrees)	Superstructure		Columns	
	$(P_D)_{Trans}$ (ksf)	$(P_D)_{Long}$ (ksf)	$(P_D)_{Trans}$ (ksf)	$(P_D)_{Long}$ (ksf)
0	0.061	0	0.049	0
15	0.054	0.007	0.043	0.006
30	0.050	0.015	0.040	0.012
45	0.040	0.020	0.032	0.016
60	0.021	0.023	0.017	0.019

Load on span =  $(6.75 + 2.67)P_D$

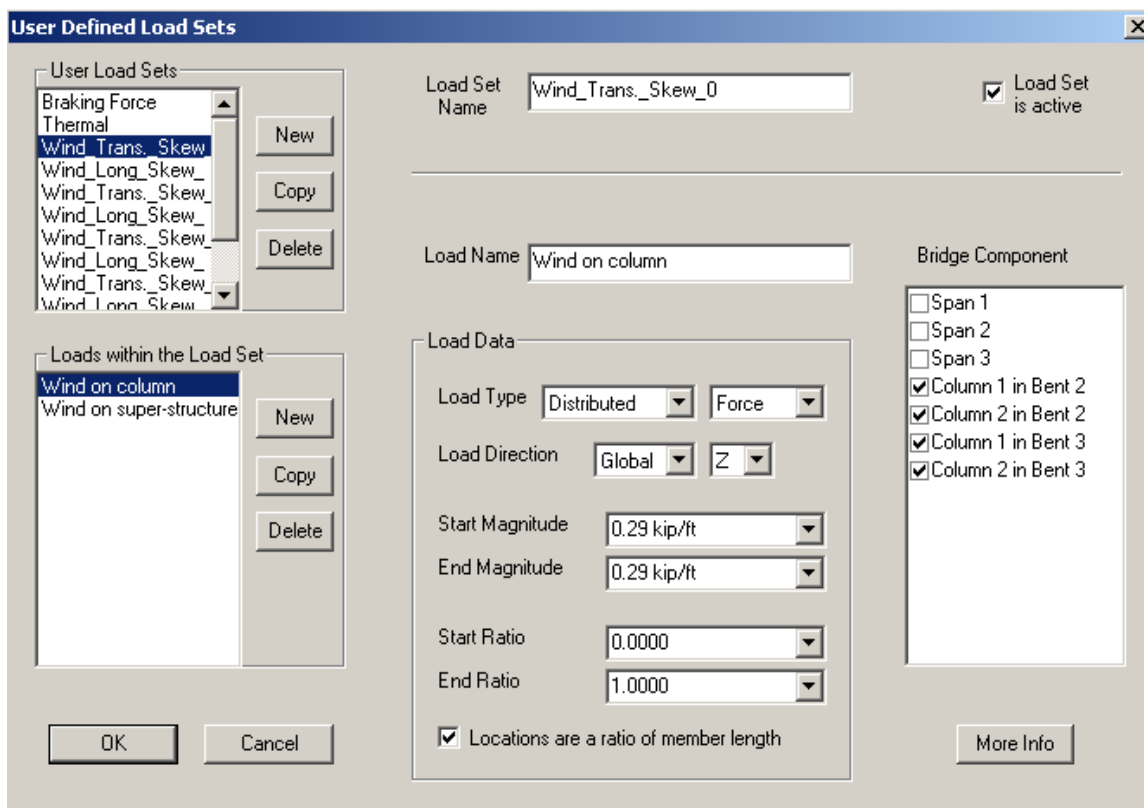
Load on columns =  $(6)P_D$

Loads on both superstructure and columns at various winds skew directions are shown in Table 13.10-16:

**Table 13.10-16 Wind Loads at Various Skew Angles of Wind**

Skew angle of wind (degrees)	Superstructure		Columns	
	$(P_D)_{Trans}$ (kip/ft)	$(P_D)_{Long}$ (kip/ft)	$(P_D)_{Trans}$ (kip/ft)	$(P_D)_{Long}$ (kip/ft)
0	0.575	0	0.294	0
15	0.509	0.066	0.258	0.036
30	0.471	0.141	0.24	0.072
45	0.377	0.188	0.192	0.096
60	0.198	0.217	0.102	0.114

Model wind as a user-defined load in CTBridge as shown below:



**Figure 13.10-3 User Defined Loads for Wind Loads**

From CTBridge output:

- Case of maximum transverse wind takes place at wind direction with skew = 0°
- Case of maximum longitudinal wind takes place at wind direction with skew = 60°

Table 13.10-17 User Loads, Unfactored Column Forces, WS Trans Skew 0°

### User Loads - Unfactored Column Forces - WS\_Trans.\_Skew\_0

#### Bent 2, Column 1

Location	AX	VY	VZ	TX	MY	MZ
ft	kip	kip	kip	kip-ft	kip-ft	kip-ft
0.00	34.4	-6.8	16.8	-0.0	0.0	0.0
11.00	34.4	-5.7	13.8	-0.0	168.0	69.0
22.00	34.4	-4.7	10.8	-0.0	303.0	126.2
33.00	34.4	-3.6	7.8	0.0	404.9	171.6
44.00	34.4	-2.5	4.8	0.0	473.8	205.1

These column forces should not be used for substructure analysis and design

Table 13.10-18 User Loads, Unfactored Column Forces, WS Trans Skew 60°.

### User Loads - Unfactored Column Forces - WS\_Long\_Skew\_ 60

#### Bent 2, Column 1

Location	AX	VY	VZ	TX	MY	MZ
ft	kip	kip	kip	kip-ft	kip-ft	kip-ft
0.00	-7.1	-27.3	-11.4	-0.0	-0.0	0.0
11.00	-7.1	-26.2	-11.0	-0.0	-123.7	294.2
22.00	-7.1	-25.0	-10.6	-0.0	-242.8	575.8
33.00	-7.1	-23.9	-10.2	0.0	-357.5	845.0
44.00	-7.1	-22.8	-9.8	0.0	-467.7	1101.5

These column forces should not be used for substructure analysis and design

- Wind on live load (WL):

Apply 0.1k/ft acting at various angles (AASHTO Table 3.8.1.3-1) as shown in Table 13.10-19:

**Table 13.10-19 Wind on Live Load (WL) at Various Angles**

Skew angle of wind (degrees)	Normal component (k-ft)	Parallel component (k-ft)
0	0.1	0
15	0.088	0.012
30	0.082	0.024
45	0.066	0.032
60	0.034	0.038

Using CTBridge for wind on live load, the results are:

- Case of maximum transverse wind takes place at skew angle of wind = 0°
- Case of maximum longitudinal wind takes place at wind direction with skew = 60°

**Table 13.10-20 User Loads, Unfactored Column Forces, WL Trans Skew 0°**

**User Loads - Unfactored Column Forces - WL\_Trans.\_Skew\_ 0**

**Bent 2, Column 1**

Location	AX	VY	VZ	TX	MY	MZ
ft	kip	kip	kip	kip·ft	kip·ft	kip·ft
0.00	6.0	-0.8	1.8	-0.0	0.0	0.0
11.00	6.0	-0.8	1.8	-0.0	20.0	8.5
22.00	6.0	-0.8	1.8	-0.0	40.0	17.0
33.00	6.0	-0.8	1.8	-0.0	60.1	25.5
44.00	6.0	-0.8	1.8	-0.0	80.1	34.0

These column forces should not be used for substructure analysis and design

**Table 13.10-21 User Loads, Unfactored Column Forces, WL Trans Skew 60°**

### User Loads - Unfactored Column Forces - WL\_Long\_Skew\_ 60

#### Bent 2, Column 1

Location ft	AX kip	VY kip	VZ kip	TX kip-ft	MY kip-ft	MZ kip-ft
0.00	-1.1	-3.9	-1.7	-0.0	-0.0	0.0
11.00	-1.1	-3.9	-1.7	-0.0	-18.4	43.3
22.00	-1.1	-3.9	-1.7	-0.0	-36.8	86.6
33.00	-1.1	-3.9	-1.7	-0.0	-55.2	129.9
44.00	-1.1	-3.9	-1.7	-0.0	-73.6	173.2

These column forces should not be used for substructure analysis and design

**Table 13.10-22 Summary of Wind Loads Reactions for Column 1 at Bent 2**

	Wind on Structure		Wind on Live Load	
	Max. Trans.	Max. Long.	Max. Trans.	Max. Long.
$M_y$ (kip-ft)	474	-468	80	-74
$M_x$ (kip-ft)	205	1102	34	173
$P$ (kip)	34	-7	6	-1

#### 13.10.2.10 Braking Force (BR)

The braking force (AASHTO 3.6.4) shall be taken as the greater of:

- 25% design truck  $= 0.25(72) = 18$  kips
- 25% design tandem  $= 0.25(50) = 12.5$  kips
- 5% design truck + lane  $= 0.05[72 + 0.64(412)] = 16.8$  kips
- 5% design tandem + lane  $= 0.05[50 + 0.64(412)] = 15.7$  kips

Controlling force  $= 18$  kips

Number of lanes  $= [58.83 - 2(1.42)] / 12 = 4.66$

Use four lanes, MPF = 0.65

Total braking force  $= 18(4)(0.65) = 46.8$  kips

Apply the braking force longitudinally then design for the moment and shear force effects. The braking force can be modeled in CTBridge as a user defined load in the direction of local  $X$  direction as shown below:

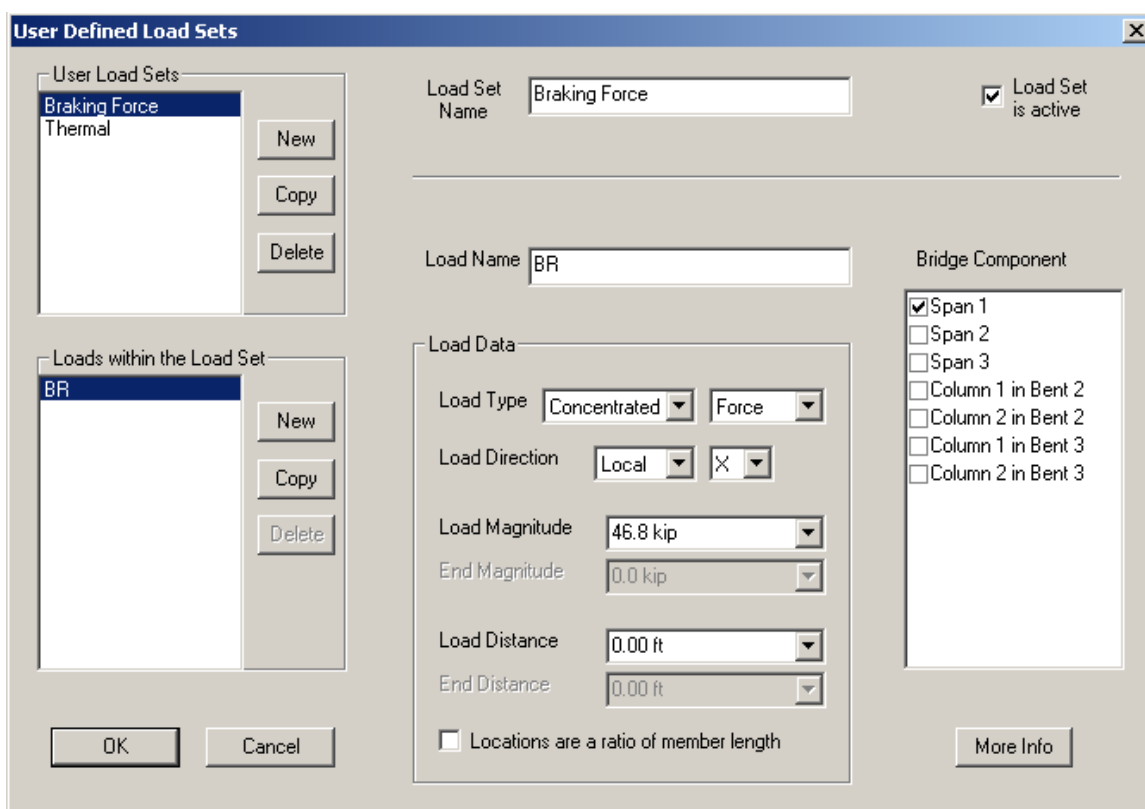


Figure 13.10-4 User Defined Loads for Braking Force

Braking forces output from CTBridge are shown in Table 13.10-23.

Table 13.10-23 User Loads, Unfactored Column Forces, Braking Force

### User Loads - Unfactored Column Forces - Braking Force

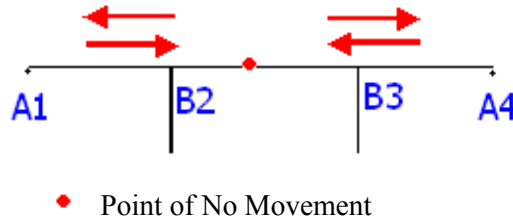
#### Bent 2, Column 1

Location ft	AX kip	VY kip	VZ kip	TX kip·ft	MY kip·ft	MZ kip·ft
0.00	-2.9	-11.7	-5.0	-0.0	-0.0	0.0
11.00	-2.9	-11.7	-5.0	-0.0	-54.9	128.9
22.00	-2.9	-11.7	-5.0	-0.0	-109.8	257.7
33.00	-2.9	-11.7	-5.0	-0.0	-164.7	386.6
44.00	-2.9	-11.7	-5.0	-0.0	-219.5	515.5

These column forces should not be used for substructure analysis and design

### 13.10.2.11 Thermal Effects (TU)

For a three-span bridge, the point of no movement is shown in Figure 13.10-5:



**Figure 13.10-5 Point of No Movement**

Design temperature ranges from 10 to 80°F (AASHTO Table 3.12.2.1-1)

For normal weight concrete  $\alpha = 0.000006/^{\circ}\text{F}$  (AASHTO 5.4.2.2)

Load factor for moment in column due to thermal movement  $\gamma_{TU} = 0.5$   
(AASHTO 3.4.1)

Thermal movement =  $(80 - 10)(0.000006)(100 \text{ ft})(12) = 0.504 \text{ in. /100 ft}$

$E = 33,000K_1 w_c^{1.5} \sqrt{f'_c}$  (AASHTO 5.4.2.4-1)

For  $f'_c = 3.6 \text{ ksi}$ ,  $E = 33,000(1)(0.15)^{1.5} \sqrt{3.6} = 3637 \text{ ksi}$

$I_g = \frac{\pi r^4}{4}$  for circular column

For 6 ft diameter column,  $I_g = \frac{\pi(3)^4}{4} = 63.6 \text{ ft}^4$

Point of no movement calculation:

$$k = \frac{3EI}{L^3}, \quad P = k\Delta \quad \text{then,} \quad P = \frac{3EI\Delta}{L^3}$$

$I$  (two columns per bent) =  $2(63.6) = 127.2 \text{ ft}^4$

$$P_{Bent2} = \frac{3(3637)(127.2)(12)^4(1)}{(44(12))^3} = 195.51 \text{ kips}$$

$$P_{Bent3} = \frac{3(3637)(127.2)(12)^4(1)}{(47(12))^3} = 160.4 \text{ kips}$$

where:

$\alpha$  = coefficient of thermal expansion

$k$  = column stiffness

$\Delta$  = lateral displacement

$L$  = column height

$P_{Bent2}$  = lateral force due to lateral displacement ( $\Delta$ ) of 1 in at bent-2

$P_{Bent3}$  = lateral force due to lateral displacement ( $\Delta$ ) of 1 in at bent-3

**Table 13.10-24 Point Of No Movement**

Units are kips and ft	Abut1	Bent2	Bent3	Abut4	SUM
$P$ at 1 inch. (kip)	0	195.5	160.4	0	355.9
Distance ( $D$ ) (ft)	0	126	294	412	832
$PD$ (kip-ft)	0	24,633	47,157.6	0	71,790.6

Distance from CL of support at Abut ( $X$ ) =  $(71790.6 / 355.9) = 201.72$  ft

Distance from point of no movement from Bent 2 =  $201.72 - 126 = 75.72$  ft

*Note:* The point of no movement can be read directly from the CTBridge output. For this example, the point of no movement is 75.72 ft from bent two, as shown in Figure 13.10-6.

### Specification Checks - Point of No Movement

Location	Distance ft
Span 2	75.72

**Figure 13.10-6 Point of No Movement**

Thermal displacement ( $\Delta_{TH}$ ) =  $(0.504 / 100) (75.72) = 0.38$  in.

$$M_{TH} = \frac{3EI_g \Delta_{TH}}{L^2} \gamma_{TU}$$

$$= \frac{3(3637)(63.6)(12)^4(0.38)}{(44(12))^2} 0.5 = 9807 \text{ kip-in.} = 817 \text{ kip-ft}$$

$$(M_{TH})_x = M \cos\theta = 817 \cos(20) = 767.6 \text{ kip-ft}$$

$$(M_{TH})_y = M \sin\theta = 817 \sin(20) = 279.4 \text{ kip-ft}$$

where:

$M_{TH}$  = column moment due to thermal expansion

$\theta$  = skew angle

$\gamma_{TU}$  = load factor for uniform temperature

### 13.10.2.12 Prestress Shortening Effects (Creep and Shrinkage)

The anticipated shortening due to prestressing effects occurs at a rate of 0.63 in. per 100 ft (MTD 7-10).

$$\text{Displacement} = 0.63 (75.72 / 100) = 0.48 \text{ in.}$$

$$M_{csh} = \frac{3EI_g \Delta}{L^2} \gamma_p = \frac{3(3637)(63.6)(12)^4 (0.48)}{(44 \times 12)^2} 0.5 = 12387 \text{ kip-in.} = 1032 \text{ kip-ft}$$

$$(M_{csh})_x = M \cos\theta = 1032 \cos(20) = 970 \text{ kip-ft}$$

$$(M_{csh})_y = M \sin\theta = 1032 \sin(20) = 353 \text{ kip-ft}$$

where:

$M_{csh}$  = column moment due to prestress shortening (creep and shrinkage)

$\gamma_p$  = load factor for permanent load due to creep and shrinkage

### 13.10.2.13 Prestress Secondary Effects (PS)

The secondary effect of prestressing after long term losses is shown in Table 13.10-25.

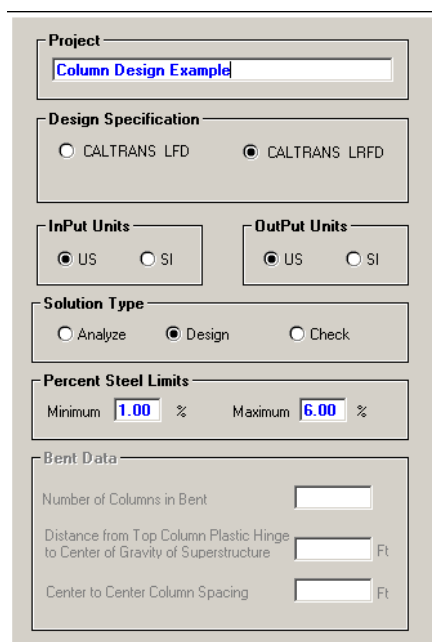
**Table 13.10-25 Prestressing Secondary Effects**

**P/S Secondary Effects After Long Term Losses for in Bent 2, Column 1 (All Frames)**

Location	AX	VY	VZ	TX	MY	MZ
ft	kip	kip	kip	kip-ft	kip-ft	kip-ft
0.00	-64.0	-2.2	-3.9	-0.0	-0.0	0.0
11.00	-64.0	-2.2	-3.9	-0.0	-43.4	24.1
22.00	-64.0	-2.2	-3.9	-0.0	-86.9	48.1
33.00	-64.0	-2.2	-3.9	0.0	-130.3	72.2
44.00	-64.0	-2.2	-3.9	0.0	-173.7	96.3

### 13.10.2.14 WinYIELD Input for Column 1 at Bent 2

Design of column reinforcement is performed by running WinYIELD starting by general form as shown in Figure 13.10-7.

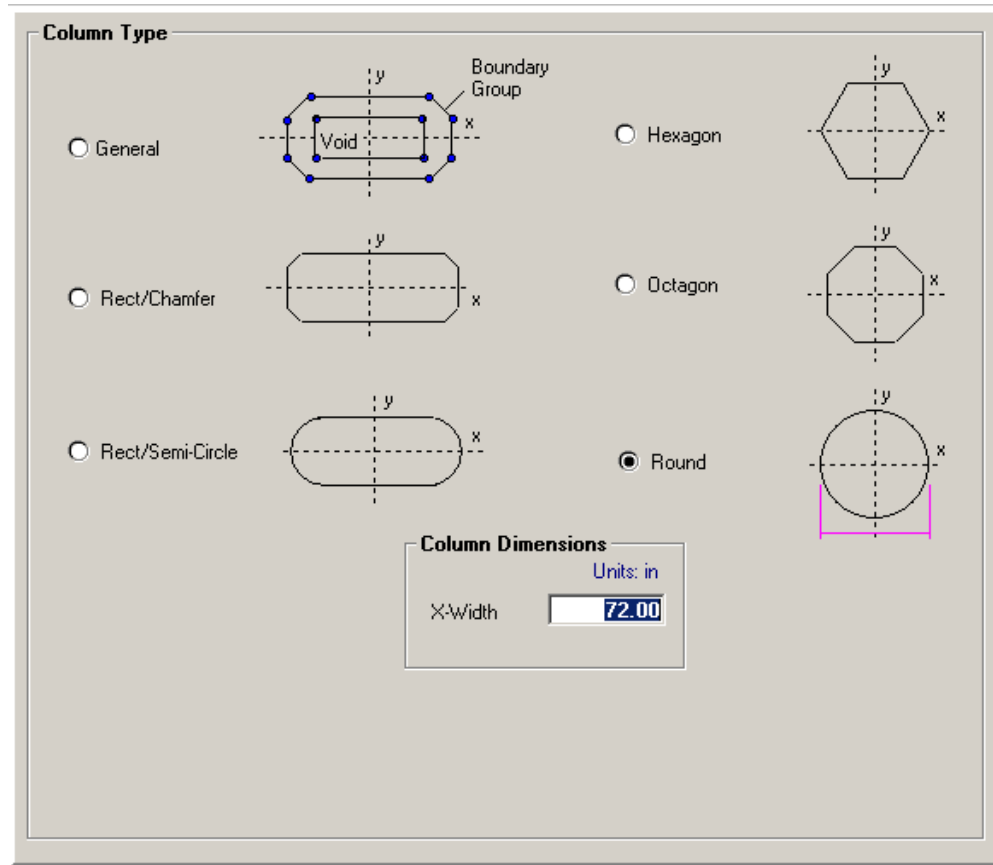


The screenshot shows the WinYIELD General Form interface. It contains several sections with input fields and radio buttons:

- Project:** A text box containing "Column Design Example".
- Design Specification:** Two radio buttons: "CALTRANS LFD" (unselected) and "CALTRANS LRFD" (selected).
- InPut Units:** Two radio buttons: "US" (selected) and "SI" (unselected).
- OutPut Units:** Two radio buttons: "US" (selected) and "SI" (unselected).
- Solution Type:** Three radio buttons: "Analyze" (unselected), "Design" (selected), and "Check" (unselected).
- Percent Steel Limits:** Two input fields: "Minimum" with value "1.00" and "Maximum" with value "6.00", both followed by a "%" symbol.
- Bent Data:** Three input fields:
  - "Number of Columns in Bent" (empty)
  - "Distance from Top Column Plastic Hinge to Center of Gravity of Superstructure" (empty) followed by "Ft"
  - "Center to Center Column Spacing" (empty) followed by "Ft"

**Figure 13.10-7 WinYIELD General Form**

Column form for circular column with diameter of 72 inches is shown in Figure 13.10-8.



The image shows a software dialog box titled "Column Type" for defining a column form. It contains several radio button options for different column shapes: General, Rect/Chamfer, Rect/Semi-Circle, Hexagon, Octagon, and Round. The "Round" option is selected. Each option is accompanied by a diagram of the respective shape with x and y axes. The "General" diagram includes a "Void" and a "Boundary Group". Below the options is a "Column Dimensions" section with a label "X-Width" and a text input field containing the value "72.00". The units are specified as "in".

**Column Type**

☐ General

☐ Rect/Chamfer

☐ Rect/Semi-Circle

☐ Hexagon

☐ Octagon

☒ Round

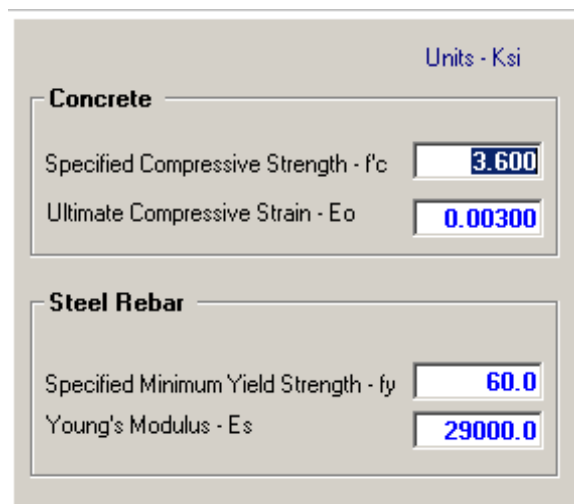
**Column Dimensions**

Units: in

X-Width: 72.00

**Figure 13.10-8 WinYIELD Column Form**

Material form (Figure 13.10-9) shows concrete specified compressive strength,  $f'_c = 3.6$  ksi and steel rebar specified minimum yield strength,  $f_y = 60$  ksi.



The image shows a software dialog box titled "WinYIELD Material Form". It has a tab labeled "Concrete" and a unit selector "Units - Ksi". Inside the "Concrete" section, there are two input fields: "Specified Compressive Strength - f'c" with a value of 3.600 and "Ultimate Compressive Strain - Eo" with a value of 0.00300. Below this is a section for "Steel Rebar" with two input fields: "Specified Minimum Yield Strength - fy" with a value of 60.0 and "Young's Modulus - Es" with a value of 29000.0.

Material	Property	Value
Concrete	Specified Compressive Strength - $f'_c$	3.600
	Ultimate Compressive Strain - $E_o$	0.00300
Steel Rebar	Specified Minimum Yield Strength - $f_y$	60.0
	Young's Modulus - $E_s$	29000.0

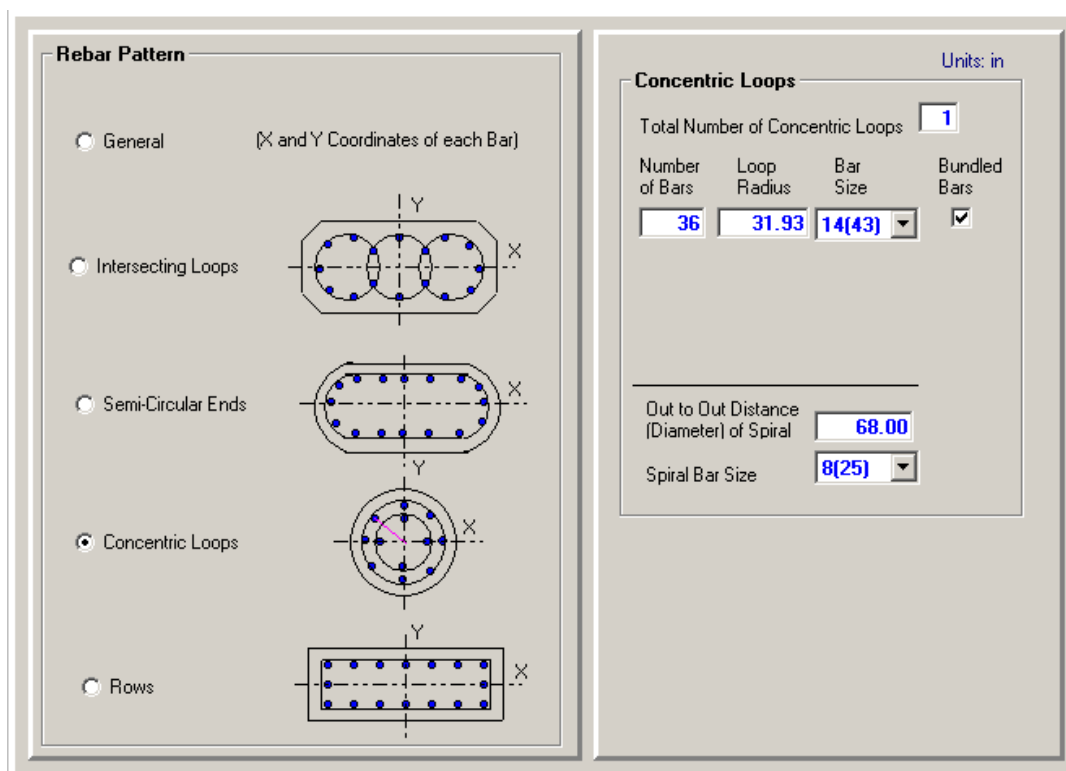
**Figure 13.10-9 WinYIELD Material Form**

Figure 13.10-10 shows the rebar form with:

Out to out distance =  $72 - 2(2) = 68$  in. (for cover = 2 in.)

Assume #14 bundle total 36 and #8 hoops

Loop radius =  $[72 - 2(2) - 2(1.13) - 2(1.88/2)]/2 = 31.9$  in.



The screenshot displays the WinYIELD Rebar Form interface, divided into two main panels: "Rebar Pattern" and "Concentric Loops".

**Rebar Pattern Panel:**

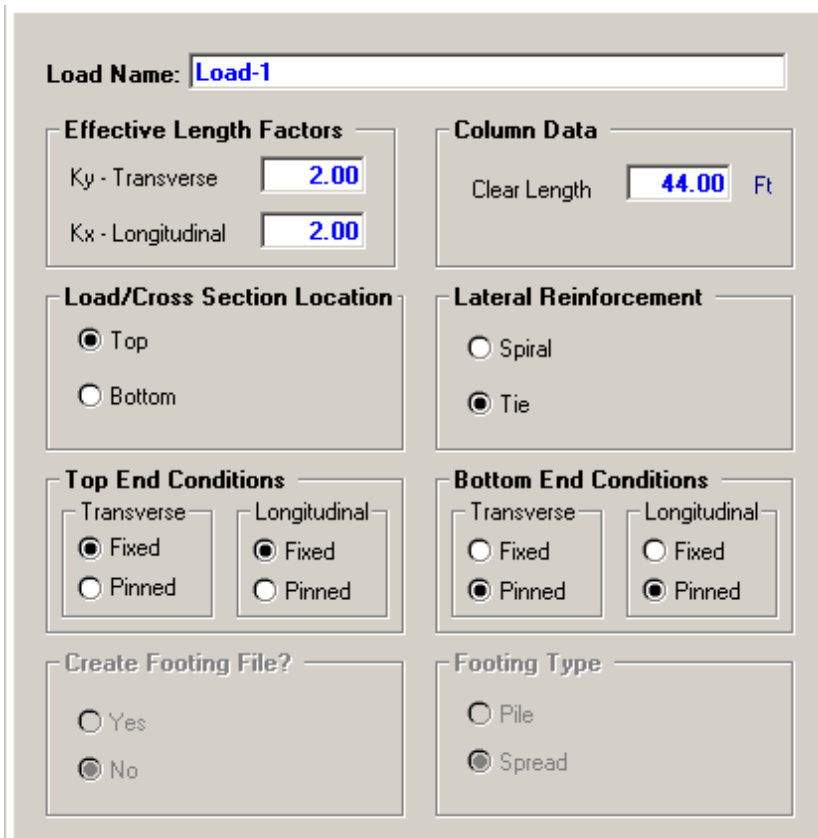
- General:** Includes a note "(X and Y Coordinates of each Bar)".
- Intersecting Loops:** Shows a diagram of intersecting loops.
- Semi-Circular Ends:** Shows a diagram of a rectangular section with semi-circular ends.
- Concentric Loops:** Selected option, showing a diagram of concentric loops.
- Rows:** Shows a diagram of bars arranged in rows.

**Concentric Loops Panel:**

- Units:** in
- Total Number of Concentric Loops:** 1
- Number of Bars:** 36
- Loop Radius:** 31.93
- Bar Size:** 14(43)
- Bundled Bars:** ☒
- Out to Out Distance (Diameter) of Spiral:** 68.00
- Spiral Bar Size:** 8(25)

**Figure 13.10-10 WinYIELD Rebar Form**

Use AASHTO Chapter 4 to determine  $K_x$  and  $K_y$ , considering AASHTO C4.6.2.5-1 to be used in load-1 form (Figure 13.10-11).



The form is titled "Load-1" and contains several sections for inputting data:

- Load Name:** A text box containing "Load-1".
- Effective Length Factors:** Two input boxes. "Ky - Transverse" is set to 2.00 and "Kx - Longitudinal" is set to 2.00.
- Column Data:** A text box for "Clear Length" is set to 44.00 Ft.
- Load/Cross Section Location:** Two radio buttons. "Top" is selected, and "Bottom" is unselected.
- Lateral Reinforcement:** Two radio buttons. "Tie" is selected, and "Spiral" is unselected.
- Top End Conditions:** Two groups of radio buttons. For "Transverse", "Fixed" is selected. For "Longitudinal", "Fixed" is selected. "Pinned" options are unselected.
- Bottom End Conditions:** Two groups of radio buttons. For "Transverse", "Pinned" is selected. For "Longitudinal", "Pinned" is selected. "Fixed" options are unselected.
- Create Footing File?:** Two radio buttons. "No" is selected, and "Yes" is unselected.
- Footing Type:** Two radio buttons. "Spread" is selected, and "Pile" is unselected.

Figure 13.10-11 WinYIELD Load-1 Form

Load-2 (Figure 13.10-12) input data is taken from Table 13.10-14.

**LRFD Limit State Loads (Unfactored)**

**Loads are Combined According To Their Sign**

Units: K, K-Ft

	Case-1 Max Transverse - My					Case-2 Max Longitudinal - Mx					Case-3 Max Axial - P				
	P-Truck PLL+M	H-Truck HLL+M	Lane Load LL	Centrifugal PC-Truck	Centrifugal HC-Truck	P-Truck PLL+M	H-Truck HLL+M	Lane LL	Centrifugal PC-Truck	Centrifugal HC-Truck	P-Truck PLL+M	H-Truck HLL+M	Lane Load LL	Centrifugal PC-Truck	Centrifugal HC-Truck
My - Trans	718	243	158			-124	23	16			-193	60	39		
Mx - Long	-262	-90	-173			-3965	997	540			-537	-195	-377		
P - Axial	-469	-158	-103			-617	-132	-95			-961	-345	-224		

Enter Permit Loads as 1.0P or 2.0P, which ever Controls.

	DC	DW	PS	PL	BR	WA	WS-Wind Str Horiz	WL-Wind Live Load	WV	FR	CR	SH	TU		
	Dead Load	Added Dead Load	Prestress Sec	Ped Live Load	Braking Force	Stream Pressure	Case-1 Max Trans	Case-2 Max Long	Case-1 Max Trans	Case-2 Max Long	Wind Str Vertical	Friction	Creep	Shrink	Temp Uniform
My - Trans	578	29	-174		-220		474	-468	80	-74				970	768
Mx - Long	-925	-110	96		516		205	1106	34	173				353	279
P - Axial	2786	163	64		3		-34	7	-6	1					

	TG	SE	Optional Elastic-EQ		IC CT CV		LRFD
	Temp Gradient	Settle	Case-1 Max Trans	Case-2 Max Long	Case-1 Max Trans	Case-2 Max Long	
My - Trans							
Mx - Long							
P - Axial							
Proj. Specific Load Factors							

(EQ Load Factor: For Live Load, BR, PL)

IM

Percent Impact

H-Truck P-Truck

33.0

Optional CALTRANS Seismic Criteria

Seismic Zone

☒ 1 ☐ 2 ☐ 3 or 4

Response Modification Factor

4.0 R

Superstructure Type

☐ Segmental

☒ Non-Segmental

Column Moment of Inertia

☐ I-Gross

☒ I-Effective

Figure 13.10-12 WinYIELD Load-2 Form

### 13.10.2.15 WinYIELD Output

Winyield output sheet (Figure 13.10-13) shows the steel reinforcement required for the column.

```
*****
* Final Results *
*****

Controlling Loading      ...   Str-IV Case 3
Nominal Axial Load Strength ... 15119 Kip
Total No. of Bars Input ...   18 Bars
Percent Steel Required   ...   1.17 Percent
Adjusted Area of Each Bar ... 2.65 in^2
Total Area of Steel Required ... 47.61 in^2
Total Number of Bars Required ... 10.6 Bars at 4.50 in^2 Per Bar

** Note: If the Bar Size is Changed, Bar Locations will Change,
and the Designer Should Consider Adjusting the Radius
of Main Steel Bar Loop and Re-Run the Program.

** Note: The Designer must Check to Ensure that Bar Spacing Limits
of Code are Satisfied.
```

Figure 13.10-13 WinYIELD Output Results

The final design could be summarized as:

Provided number of bars = 18 bundle > required number of bars = 10.6 (OK)

Min. clearance and spacing for #14 bundle horizontally = 7.5 in.

Distance between bundles =  $2\pi (31.93) / 18 = 11.1$  in. > 7.5 in. (OK)

### 13.10.3 Shear Design for Transverse Reinforcement ( $A_v$ )

The procedure of determining column transverse reinforcement is presented in consequent sections.

#### 13.10.3.1 Longitudinal Analysis

From CTBridge output (Tables 13.10-26 and 13.10-27), determine longitudinal shear ( $V_y$ ) and moment ( $M_z$ ) at top and bottom of columns for DC and DW. Combine output in Table 3.10-28.

**Table 13.10-26 Dead Load, Unfactored Column Forces**

#### **Dead Load - Unfactored Column Forces - Final**

<b>Bent 2, Column 1</b>						
<b>Location</b>	<b>AX</b>	<b>VY</b>	<b>VZ</b>	<b>TX</b>	<b>MY</b>	<b>MZ</b>
<b>ft</b>	<b>kip</b>	<b>kip</b>	<b>kip</b>	<b>kip-ft</b>	<b>kip-ft</b>	<b>kip-ft</b>
<b>0.00</b>	-1501.8	21.0	1.1	0.0	0.0	-0.0
<b>11.00</b>	-1455.2	21.0	1.1	0.0	12.6	-231.3
<b>22.00</b>	-1408.5	21.0	1.1	0.0	25.1	-462.6
<b>33.00</b>	-1361.9	21.0	1.1	-0.0	37.7	-693.9
<b>44.00</b>	-1315.2	21.0	1.1	-0.0	50.3	-925.2

**Table 13.10-27 Additional Dead Load, Unfactored Column Forces**

#### **Additional Dead Load - Unfactored Column Forces**

<b>Bent 2, Column 1</b>						
<b>Location</b>	<b>AX</b>	<b>VY</b>	<b>VZ</b>	<b>TX</b>	<b>MY</b>	<b>MZ</b>
<b>ft</b>	<b>kip</b>	<b>kip</b>	<b>kip</b>	<b>kip-ft</b>	<b>kip-ft</b>	<b>kip-ft</b>
<b>0.00</b>	-161.1	2.5	0.1	0.0	0.0	-0.0
<b>11.00</b>	-161.1	2.5	0.1	0.0	1.6	-27.5
<b>22.00</b>	-161.1	2.5	0.1	0.0	3.2	-55.1
<b>33.00</b>	-161.1	2.5	0.1	-0.0	4.7	-82.6
<b>44.00</b>	-161.1	2.5	0.1	-0.0	6.3	-110.1

**Table 13.10-28 Longitudinal Shear ( $V_y$ ) and Longitudinal Moment ( $M_z$ ) for DC and DW**

	Top of Column		Bottom of Column	
	DC	DW	DC	DW
$V_y$ (kip)	21	2.5	21	2.5
$M_z$ (kip-ft)	-925.2	-110.1	0	0

Determine maximum longitudinal shear ( $V_y$ ) and associated moment ( $M_z$ ) for design vehicular live loads at top and bottom of the bent unfactored reactions for one lane as shown in Table 13.10-29.

**Table 13.10-29 Unfactored Bent Reactions For Design Vehicle**

### Live Load - Controlling Unfactored Bent Reactions

#### Bent 2 Reactions - LRFD Design Vehicle

#### No Dynamic Load Allowance - Single Lane

Location	Primary DOF	T / L	AX kip	VY kip	VZ kip	MY kip-ft	MZ kip-ft
Col Bots	VY-	Truck	-44.34	-7.55	-0.11	-0.00	0.00
		Lane	-41.57	-5.42	-0.05	-0.00	0.00
Col Bots	VY+	Truck	-58.56	10.34	0.19	0.00	-0.00
		Lane	-59.85	7.64	0.15	0.00	-0.00
Col Tops	VY-	Truck	-44.34	-7.55	-0.11	-4.99	332.16
		Lane	-41.57	-5.42	-0.05	-2.29	238.51
Col Tops	VY+	Truck	-58.56	10.34	0.19	8.44	-454.77
		Lane	-59.85	7.64	0.15	6.48	-336.13

Determine maximum longitudinal shear ( $V_y$ ) and associated moment ( $M_z$ ) for permit vehicular live loads at top and bottom of the bent unfactored reactions for one lane as shown in Table 13.10-30.

**Table 13.10-30 Unfactored Bent Reactions For Permit Vehicle**

<b>Bent 2 Reactions - LRFD Permit Vehicle</b>							
<b>No Dynamic Load Allowance - Single Lane</b>							
<b>Location</b>	<b>Primary DOF</b>	<b>T / L</b>	<b>AX kip</b>	<b>VY kip</b>	<b>VZ kip</b>	<b>MY kip-ft</b>	<b>MZ kip-ft</b>
Col Bots	VY-	Truck	-235.51	-16.19	2.83	0.00	0.00
Col Bots	VY+	Truck	-231.37	33.78	0.58	0.00	-0.00
Col Bots	VZ-	Truck	19.75	-12.28	-3.09	-0.00	0.00
Col Bots	VZ+	Truck	-235.51	-16.19	2.83	0.00	0.00
Col Tops	AX-	Truck	-360.23	4.57	0.56	24.69	-201.20
Col Tops	AX+	Truck	19.75	-12.28	-3.09	-136.17	540.25
Col Tops	MY-	Truck	19.75	-12.28	-3.09	-136.17	540.25
Col Tops	MY+	Truck	-235.51	-16.19	2.83	124.67	712.36
Col Tops	MZ-	Truck	-231.37	33.78	0.58	25.31	-1486.10
Col Tops	MZ+	Truck	-235.51	-16.19	2.83	124.67	712.36
Col Tops	VY-	Truck	-235.51	-16.19	2.83	124.67	712.36
Col Tops	VY+	Truck	-231.37	33.78	0.58	25.31	-1486.10

Re-arrange the longitudinal shear and moment output from CTBridge are for two columns (Table 13.10-31).

**Table 13.10-31 Unfactored Bent Reactions for One Lane, Dynamic Load Allowance Factors Not Included**

Design Vehicle			Permit Vehicle	
Maximum longitudinal shear and associated longitudinal moment at top of the column			Maximum longitudinal shear and associated longitudinal moment at top of the column	
	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)
Truck	10.3	-455	-12.28	540.25
Lane	7.6	-336		
Maximum longitudinal shear and associated longitudinal moment at bottom of the column			Maximum longitudinal shear and associated longitudinal moment at bottom of the column	
	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)
Truck	10.3	0	33.78	0
Lane	7.6	0		

Apply dynamic allowance factor to Table 13.10-31 for one column as shown in Table 13.10-32.

**Table 13.10-32 Unfactored Column Longitudinal Shear and Associated Longitudinal Moment for One Lane, Including Dynamic Load Allowance Factors.**

Design Vehicle			Permit Vehicle	
Maximum longitudinal shear and associated longitudinal moment at top of the column			Maximum longitudinal shear and associated longitudinal moment at top of the column	
	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)
Truck	6.8	-303	-7.7	338
Lane	3.8	-168		
Maximum longitudinal shear and associated longitudinal moment at bottom of the column			Maximum longitudinal shear and associated longitudinal moment at bottom of the column	
	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)
Truck	6.8	0	21	0
Lane	3.8	0		

### 13.10.3.2 Transverse Analysis

CSiBridge output for load cases of dead load (DC) and added dead load (ADL) is shown in Table 13.10-33.

**Table 13.10-33 Transverse Shear ( $V_2$ ) and Moment ( $M_3$ ) at Top and Bottom of Columns due to Dead Load (DC) and Added Dead Load (DW)**

TABLE: Element Forces - Frames												
Frame	Station	OutputCase	CaseType	StepType	P	V2	V3	T	M2	M3	FrameElem	
Text	ft	Text	Text	Text	Kip	Kip	Kip	Kip-ft	Kip-ft	Kip-ft	Text	Text
1	0	DEAD	LinStatic		-2785.814	-10.497	0	0	0	0	1-1	
1	4.8894	DEAD	LinStatic		-2785.814	-10.497	0	0	0	51.3239	1-1	
1	9.7789	DEAD	LinStatic		-2785.814	-10.497	0	0	0	102.6478	1-1	
1	14.6683	DEAD	LinStatic		-2785.814	-10.497	0	0	0	153.9717	1-1	
1	19.5578	DEAD	LinStatic		-2785.814	-10.497	0	0	0	205.2956	1-1	
1	24.4472	DEAD	LinStatic		-2785.814	-10.497	0	0	0	256.6195	1-1	
1	29.3367	DEAD	LinStatic		-2785.814	-10.497	0	0	0	307.9435	1-1	
1	34.2261	DEAD	LinStatic		-2785.814	-10.497	0	0	0	359.2674	1-1	
1	39.1156	DEAD	LinStatic		-2785.814	-10.497	0	0	0	410.5913	1-1	
1	44.005	DEAD	LinStatic		-2785.814	-10.497	0	0	0	461.9152	1-1	
1	0	ADL	LinStatic		-162.5	-0.523	0	0	0	-3.553E-15	1-1	
1	4.8894	ADL	LinStatic		-162.5	-0.523	0	0	0	2.5561	1-1	
1	9.7789	ADL	LinStatic		-162.5	-0.523	0	0	0	5.1122	1-1	
1	14.6683	ADL	LinStatic		-162.5	-0.523	0	0	0	7.6682	1-1	
1	19.5578	ADL	LinStatic		-162.5	-0.523	0	0	0	10.2243	1-1	
1	24.4472	ADL	LinStatic		-162.5	-0.523	0	0	0	12.7804	1-1	
1	29.3367	ADL	LinStatic		-162.5	-0.523	0	0	0	15.3365	1-1	
1	34.2261	ADL	LinStatic		-162.5	-0.523	0	0	0	17.8926	1-1	
1	39.1156	ADL	LinStatic		-162.5	-0.523	0	0	0	20.4486	1-1	
1	44.005	ADL	LinStatic		-162.5	-0.523	0	0	0	23.0047	1-1	

Combine output in Table 3.10-34.

**Table 13.10-34 Transverse Shear ( $V_2$ ) and Moment ( $M_3$ ) for DC and DW**

	Top of column		Bottom of column	
	DC	DW	DC	DW
$V_2$ (kip)	-10.5	-0.5	-10.5	-0.5
$M_3$ (kip-ft)	462	23	0	0

CSiBridge output for maximum shear ( $V_2$ ) and associated and moment ( $M_3$ ) for design vehicle including dynamic load allowance as shown in Table 13.10-35.

**Table 13.10-35 Maximum Shear ( $V_2$ ) and Associated Moment ( $M_3$ ) for Design Vehicle**

TABLE: Element Forces - Frames											
Frame	Station	OutputCase	CaseType	StepType	P	V2	V3	T	M2	M3	FrameElem
Text	ft	Text	Text	Text	Kip	Kip	Kip	Kip-ft	Kip-ft	Kip-ft	Text
1	24.4472	DESIGN	LinMoving	Max V2	-368.676	4.822	0	0	0	-117.8954	1-1
1	29.3367	DESIGN	LinMoving	Max V2	-368.676	4.822	0	0	0	-141.4745	1-1
1	34.2261	DESIGN	LinMoving	Max V2	-368.676	4.822	0	0	0	-165.0536	1-1
1	39.1156	DESIGN	LinMoving	Max V2	-368.676	4.822	0	0	0	-188.6327	1-1
1	44.005	DESIGN	LinMoving	Max V2	-368.676	4.822	0	0	0	-212.2118	1-1
1	0	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	0	1-1
1	4.8894	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	44.4949	1-1
1	9.7789	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	88.9898	1-1
1	14.6683	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	133.4847	1-1
1	19.5578	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	177.9796	1-1
1	24.4472	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	222.4745	1-1
1	29.3367	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	266.9693	1-1
1	34.2261	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	311.4642	1-1
1	39.1156	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	355.9591	1-1
1	44.005	DESIGN	LinMoving	Min V2	-261.255	-9.1	0	0	0	400.454	1-1

CSiBridge output for maximum shear ( $V_2$ ) and associated and moment ( $M_3$ ) for permit vehicle including dynamic load allowance as shown in Table 13.10-36.

**Table 13.10-36 Maximum Shear ( $V_2$ ) and Associated Moment ( $M_3$ ) for Permit Vehicle**

TABLE: Element Forces - Frames											
Frame	Station	OutputCase	CaseType	StepType	P	V2	V3	T	M2	M3	FrameElem
Text	ft	Text	Text	Text	Kip	Kip	Kip	Kip-ft	Kip-ft	Kip-ft	Text
1	9.7789	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-84.5853	1-1
1	14.6683	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-126.8779	1-1
1	19.5578	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-169.1706	1-1
1	24.4472	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-211.4632	1-1
1	29.3367	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-253.7559	1-1
1	34.2261	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-296.0485	1-1
1	39.1156	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-338.3412	1-1
1	44.005	PERMIT	LinMoving	Max V2	-661.276	8.65	0	0	0	-380.6338	1-1
1	0	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	0	1-1
1	4.8894	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	79.8083	1-1
1	9.7789	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	159.6166	1-1
1	14.6683	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	239.4249	1-1
1	19.5578	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	319.2332	1-1
1	24.4472	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	399.0415	1-1
1	29.3367	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	478.8498	1-1
1	34.2261	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	558.6581	1-1
1	39.1156	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	638.4664	1-1
1	44.005	PERMIT	LinMoving	Min V2	-468.601	-16.323	0	0	0	718.2747	1-1

Re-arrange the transverse shear and moment output from CSiBridge in Table 13.10-37.

**Table 13.10-37 Unfactored Column Reaction, Including Dynamic Load Allowance Factors**

Design Vehicle			Permit Vehicle	
Maximum transverse shear and associated transverse moment at top of the column			Maximum transverse shear and associated transverse moment at top of the column	
	$(V_2)_{max}$ (kip)	$(M_3)_{assoc}$ (kip-ft)	$(V_2)_{max}$ (kip)	$(M_3)_{assoc}$ (kip-ft)
Truck	-9.1	400	-16.3	718
Maximum transverse shear and associated transverse moment at bottom of the column			Maximum transverse shear and associated transverse moment at bottom of the column	
	$(V_2)_{max}$ (kip)	$(M_3)_{assoc}$ (kip-ft)	$(V_2)_{max}$ (kip)	$(M_3)_{assoc}$ (kip-ft)
Truck	-9.1	0	-16.3	0

Use the procedure shown in 13.7.4 and arrange output in Table 13.10-38.

**Table 13.10-38 Unfactored Column Reactions, Including Dynamic Load Allowance Factor**

Design Vehicle			Permit Vehicle	
Maximum transverse shear and associated longitudinal moment at top of the column			Maximum transverse shear and associated longitudinal moment at top of the column	
Truck	-5.5	243	-16.3	718
Lane	-3.6	157		
Maximum transverse shear and associated longitudinal moment at bottom of the column			Maximum transverse shear and associated longitudinal moment at bottom of the column	
	$(V_2)_{max}$ (kip)	$(M_3)_{assoc}$ (kip-ft)	$(V_2)_{max}$ (kip)	$(M_3)_{assoc}$ (kip-ft)
Truck	-5.5	0	-16.3	0
Lane	-3.6	0		

### 13.10.3 Total Longitudinal Shear and Associated Moments

Total column longitudinal total shear and associated moment as per 13.8.3 is presented in Table 13.10-39.

**Table 13.10-39 Unfactored Column Total Longitudinal Shear and Associated Longitudinal Moment, Including Dynamic Load Allowance Factors**

Design Vehicle			Permit Vehicle	
Maximum longitudinal shear and associated longitudinal moment at top of the column			Maximum longitudinal shear and associated longitudinal moment at top of the column	
	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)
Truck	31	-1367	-12	519
Lane	17	-759		
Maximum longitudinal shear and associated longitudinal moment at bottom of the column			Maximum longitudinal shear and associated longitudinal moment at bottom of the column	
	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)
Truck	31	0	32	0
Lane	17	0		

### 13.10.3.9 Summary of Column Shear Loads

Column shear loads are summarized in Table 13.10-40.

**Table 13.10-40 Longitudinal Shear and Associated Longitudinal Moment**

Load Case	Top of Column		Bottom of Column	
	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)	$(V_y)_{max}$ (kip)	$(M_z)_{assoc}$ (kip-ft)
DC	21	-925	21	0
DW	2.5	-110	2.5	0
H-Truck	31	-1367	31	0
Lane	17	-759	17	0
P-Truck	-12	519	32	0

**Table 13.10-41 Transverse Shear and Associated Transverse Moment.**

Load Case	Top of Column		Bottom of Column	
	$(V_z)_{max}$ (kip)	$(M_y)_{assoc}$ (kip-ft)	$(V_z)_{max}$ (kip)	$(M_y)_{assoc}$ (kip-ft)
DC	-10.5	462	-10.5	0
DW	-0.5	23	-0.5	0
H-Truck	-5.8	258	-5.8	0
Lane	-3.3	143	-3.3	0
P-Truck	-16.3	718	-16.3	0

Since this example uses circular columns, the design shears and moments should be taken as the square root of the sum of the squares:

**Table 13.10-42 Square Root of the Sum of the Squares**

Load Case	Top of Column		Bottom of Column	
	$V$ (kip)	$(M)_{assoc}$ (kip-ft)	$V$ (kip)	$(M)_{assoc}$ (kip-ft)
DC	23	1034	23	0
DW	3	112	3	0
H-Truck	32	1392	32	0
Lane	17	772	17	0
P-Truck	20	886	36	0

### 13.10.3.10 Strength Shear Limit States

Determine strength I and strength II limit states for shear and associated moments.

- Strength I:

$$V_u = 1.25 (23) + 1.5 (3) + 1.75 (32 + 17) = 119 \text{ kips} \quad (\text{controls})$$

$$M_u = 1.25 (1034) + 1.5 (112) + 1.75 (1392 + 772) = 5248 \text{ kips}$$

- Strength II:

$$V_u = 1.25 (23) + 1.5 (3) + 1.35 (20) = 60 \text{ kips}$$

$$M_u = 1.25 (1034) + 1.5 (112) + 1.35 (886) = 2,657 \text{ kip-ft}$$

$$V_n = V_c + V_s \quad (\text{AASHTO 5.8.3.3-1})$$

$$V_s = \frac{A_v f_y d_v}{s} \cot \theta \quad (\text{AASHTO 5.8.3.3-4})$$

$$v_u = \frac{V_u}{\phi b_v d_v} \quad (\text{AASHTO 5.8.2.9-1})$$

Column loop radius = 31.93 in. (from WinYIELD input)

Using simplified procedure for nonprestressed sections (AASHTO 5.8.3.4.1)

$$\beta = 2$$

$$\theta = 45^\circ$$

$$V_c = 0.0316 \beta \sqrt{f'_c} b_v d_v = 0.0316(2) \sqrt{3.6}(72)(50.16) = 433 \text{ kips} > 119 \text{ kips}$$

where:

$A_v$  = area of shear reinforcement within a distance  $s$  (in.<sup>2</sup>)

$b_v$  = effective web width

$d_v$  = effective shear depth

$s$  = spacing of transverse reinforcement measured in a direction parallel to the longitudinal reinforcement (in.)

$V_c$  = concrete shear capacity

$V_n$  = nominal shear capacity

$V_s$  = transverse shear reinforcement capacity

$V_u$  = factored shear force

$M_u$  = factored moment

$\beta$  = factor indicating ability of diagonally cracked concrete to transmit tension and shear as specified in article 5.8.3.4

Use minimum shear reinforcement (AASHTO 5.8.2.5-1).

$$\left( \frac{A_v}{s} \right)_{\min} = 0.0316 \frac{\sqrt{f'_c}}{f_y} b_v = 0.0316 \frac{\sqrt{3.6}}{60} \times 72 = 0.072 \text{ in.}^2 / \text{in.}$$

$A_v = 0.79 \text{ in.}^2$  for #8 hoops, so

$$s_{\min} = \frac{0.79}{0.072} = 11 \text{ in.} \quad (\text{Use } s = 6 \text{ in.})$$

Check maximum spacing:

$$\text{For } \frac{v_u}{f'_c} < 0.125 \quad S_{max} = 0.8 d_v \leq 18 \text{ in.} \quad (\text{CA 5.8.2.7-1})$$

$$\frac{v_u}{f'_c} \geq 0.125 \quad S_{max} = 0.4 d_v \leq 12 \text{ in.} \quad (\text{AASHTO 5.8.2.7-2})$$

$$\text{Since } \frac{v_u}{f'_c} = \frac{0.0483}{3.6} = 0.0134 < 0.125, \text{ then } S_{max} = 0.8 (50.16) = 40.1 \text{ in.} > 18 \text{ in.}$$

$$S_{max} = 18 \text{ in.} > 11 \text{ in.} \quad (\text{OK})$$

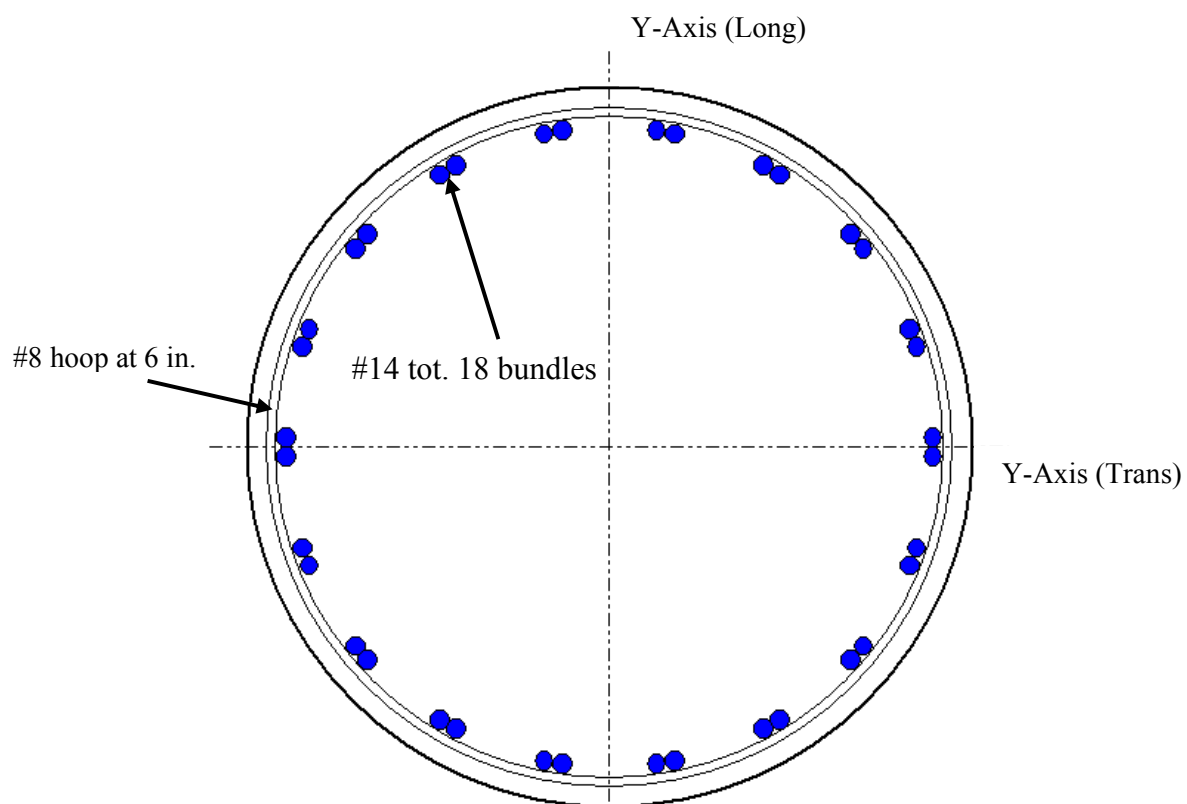
*Note:* Use #8 hoops @ 6 in. Seismic shear demands should be checked per the current SDC. Column confinement/shear steel, in most normal cases, will be governed by the plastic hinge shear.

Check shear-flexure interaction:

$$A_s f_y \geq \frac{M_u}{\phi d_v} + \left[ \frac{V_u}{\phi} - 0.5 V_s \right] \cot \theta \quad (\text{AASHTO 5.8.3.5.3-1})$$

$$2(18)(2.25)(60)^3 \frac{5248(12)}{0.9(50.16)} + \left[ \frac{117}{0.9} - 0 \right] \cot 45$$

4860 kips  $\geq$  1525 kips (OK), then #14 tot. 18 bundle as shown in Figure 13.10-14 are OK



**Figure 13.10-14 Column Details—Reinforcement of Column**

## NOTATION

$A_g$	=	gross area of section (in. <sup>2</sup> ) (13.6.2)
$A_s$	=	main column reinforcement (13.10.2)
$A_{st}$	=	total area of main column reinforcement (in. <sup>2</sup> ) (13.6.2)
$A_v$	=	area of shear reinforcement within a distance $s$ (in <sup>2</sup> ) (13.10.3.10)
$A_x$	=	axial load (13.7.1)
$b_v$	=	effective web width (13.10.3.10)
$C_m$	=	a factor, which relates the actual moment diagram to an equivalent uniform moment diagram, is typically taken as 1 (13.5.1)
$d_v$	=	effective shear depth (13.10.3.10)
$E_c$	=	the elastic modulus of concrete (ksi) (13.5.1)
$E_s$	=	elastic modulus of reinforcement (ksi) (13.5.1)
$f'_c$	=	specified strength of concrete at 28 days, unless another age is specified (ksi) (13.6.2)
$f_y$	=	specified yield strength of reinforcement (ksi) (13.6.2)
$I$	=	moment of inertia about axis under consideration (in. <sup>4</sup> ) (13.5.1)
$I_g$	=	the gross moment of inertia (in. <sup>4</sup> ) (13.5.1)
$I_s$	=	moment of inertia of longitudinal steel about neutral axis (ksi) (13.5.1)
$K$	=	the effective length factor (13.2)
$k$	=	column stiffness (k/in)(13.10.2.11)
$L$	=	column height (13.10.2.11)
$l_u$	=	the unsupported length of a compression member (in.) (13.2)
$M_{TH}$	=	column moment due to thermal expansion (13.10.2.11)
$M_{csh}$	=	column moment due to prestress shortening (creep and shrinkage) (13.10.2.11)
$M_1$	=	the smaller end moment, should be positive for single curvature flexure (13.5)
$M_2$	=	the larger end moment, should be positive for single curvature flexure (13.5)
$M_{2b}$	=	moment on compression member due to factored gravity loads that result no sidesway, always positive (kip-ft) (13.5.1)
$M_{2s}$	=	moment on compression member due to factored lateral or gravity loads that result in sidesway, $\Delta$ , greater than $l_u/1500$ , always positive (kip-ft) (13.5.1)
$M_3$	=	transverse moment (13.7.2)
$M_b$	=	balanced moment resistance at balanced strain condition (13.6.1)

$M_c$	=	magnified factored moment (13.5.1)
$M_o$	=	nominal flexural resistance of a section at zero eccentricity (13.6.1)
$M_n$	=	nominal flexural resistance (13.6.1)
$M_{rx}$	=	uniaxial factored flexural resistance of a section about $x$ -axis corresponding to the eccentricity produced by the applied factored axial load and moment (13.6.2)
$M_{ry}$	=	uniaxial factored flexural resistance of a section about $y$ -axis corresponding to the eccentricity produced by the applied factored axial load and moment (13.6.2)
$M_u$	=	factored moment (13.10.3.10)
$M_{ux}$	=	factored applied moment about $x$ -axis (kip-in.) (13.6.2)
$M_{uy}$	=	factored applied moment about $y$ -axis (kip-in.) (13.6.2)
$M_y$	=	transverse moment (13.7.2)
$M_z$	=	longitudinal moment (13.7.1)
$P$	=	column axial load (13.7.2)
$P_B$	=	base wind pressure, corresponding to $V_B = 100$ mph (13.10.2.9)
$P_b$	=	balanced axial resistance at balanced strain condition (13.6.1)
$P_{Bent2}$	=	lateral force due to lateral displacement ( $\Delta$ ) of 1 in at bent-2 (13.10.2.11)
$P_{Bent3}$	=	lateral force due to lateral displacement ( $\Delta$ ) of 1 in at bent-3 (13.10.2.11)
$P_D$	=	wind pressure on structures (13.10.2.9)
$P_e$	=	Euler buckling load (13.5.1)
$P_n$	=	nominal axial resistance, with or without flexure (13.6.2)
$P_o$	=	nominal axial resistance of a section at 0 eccentricity (kip) (13.6.1)
$P_r$	=	factored axial resistance (13.6.2)
$P_{rx}$	=	factored axial resistance determined on the basis that only eccentricity $e_y$ is present (kip) (13.6.2)
$P_{rxy}$	=	factored axial resistance in biaxial flexure (kip) (13.6.2)
$P_{ry}$	=	factored axial resistance determined on the basis that only eccentricity $e_x$ is present (kip) (13.6.2)
$P_u$	=	factored axial load (kip) (13.5.1)
$r$	=	radius of gyration (in.) (13.2)
$R1$	=	truck load of design vehicle (13.7.3)
$R2$	=	lane load of design vehicle (13.7.3)

$S$	=	spacing of transverse reinforcement measured in a direction parallel to the longitudinal reinforcement (in) (13.10.3.10)
$V_2$	=	transverse analysis (13.8.2)
$V_B$	=	base wind velocity of 100 mph at 30 ft height (13.10.2.9)
$V_c$	=	concrete shear capacity (13.10.3.10)
$V_{DZ}$	=	design wind velocity (mph) at design elevations (13.10.2.9)
$V_n$	=	nominal shear capacity (13.10.3.10)
$V_o$	=	friction velocity (mph) (13.10.2.9)
$V_s$	=	transverse shear reinforcement capacity (13.10.3.10)
$V_u$	=	factored shear force (13.10.3.10)
$V_y$	=	longitudinal shear (13.8.1)
$Z$	=	height of structure (ft) at which wind loads are being calculated as measured from low ground, or from water level, > 30 ft (13.10.2.9)
$Z_o$	=	friction length (ft) upstream fetch (13.10.2.9)
$\alpha$	=	coefficient of thermal expansion (13.10.2.11)
$\beta$	=	factor indicating ability of diagonally cracked concrete to transmit tension and shear (13.10.3.10)
$\beta_d$	=	ratio of maximum factored permanent moment to the maximum factored total load moment, always positive (13.5.1)
$\gamma_p$	=	load factor for permanent load due to creep and shrinkage (13.10.2.12)
$\gamma_{TU}$	=	load factor for uniform temperature (13.10.2.11)
$\Delta$	=	lateral displacement (13.5.1)
$\epsilon_c$	=	compression strain of the concrete (13.6.1)
$\epsilon_y$	=	yield strain of the steel (13.6.1)
$\delta_b$	=	moment magnification factor for compression member braced against sidesway (13.5.1)
$\delta_s$	=	moment magnification factor for compression member not braced against sidesway (13.5.1)
$\theta$	=	skew angle (13.10.2.11)
$\phi$	=	resistance factor specified in AASHTO 5.5.4.2 (13.6.2)
$\phi_k$	=	stiffness reduction factor; 0.75 for concrete members and 1 for steel members (13.5.1)

## REFERENCES

1. AASHTO, (2012). *AASHTO LRFD Bridge Design Specifications*, American Association of State Highway and Transportation Officials, 6th Edition, Washington, DC.
2. Caltrans, (2014). *California Amendments to AASHTO LRFD Bridge Design Specifications—Sixth Edition*, California Department of Transportation, Sacramento, CA.
3. Caltrans, (2013). *Caltrans Seismic Design Criteria—Version 1.7*, California Department of Transportation, Sacramento, CA.
4. Caltrans, (2008). *WinYIELD (2008): Column Live Load Input Procedure*, California Department of Transportation, Sacramento, CA.
5. Chen, W.F. and Duan, L. Ed. (2014). *Bridge Engineering Handbook—2<sup>nd</sup> Edition*, CRC press, Boca Raton, FL.
6. CSI, (2015). *CSiBridge 2015*, Version 17.0.0, Computers and Structures, Inc. Walnut Creek, CA.
7. MacGregor, J.G. (1988). *Reinforced Concrete Mechanics and Design*, Prentice-Hall, Englewood Cliffs, NJ.